IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CIF LICENSING, LLC, d/b/a GE LICENSING,	)	C.A. No. 07-170 (JJF)
Plaintiff,	)	
v.	)	
AGERE SYSTEMS INC.,	)	
Defendant.	)	

APPENDIX OF EXHIBITS TO PLAINTIFF CIF LICENSING, LLC, d/b/a GE <u>LICENSING'S OPENING CLAIM CONSTRUCTION BRIEF</u>

VOLUME 2 – EXHIBITS F-P

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Dated: April 28, 2008

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

CERTIFICATE OF SERVICE

I, Philip A. Rovner, hereby certify that on April 28, 2008, the within document was filed with the Clerk of the Court using CM/ECF; that the document was served on the following party as indicated; and that the document is available for viewing and downloading from CM/ECF.

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EXHIBIT F

INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

V.34

(09/94)

DATA COMMUNICATION OVER THE TELEPHONE NETWORK

A MODEM OPERATING AT DATA SIGNALLING RATES OF UP TO 28 800 bit/s FOR USE ON THE GENERAL SWITCHED TELEPHONE NETWORK AND ON LEASED POINT-TO-POINT 2-WIRE TELEPHONE-TYPE CIRCUITS

ITU-T Recommendation V.34

(Previously "CCITT Recommendation")

FOREWORD

The ITU-T (Telecommunication Standardization Sector) is a permanent organ of the International Telecommunication Union (ITU). The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1 (Helsinki, March 1-12, 1993).

ITU-T Recommendation V.34 was prepared by ITU-T Study Group 14 (1993-1996) and was approved under the WTSC Resolution No. 1 procedure on the 20th of September 1994.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

CONTENTS

Recommendation V.34

A MODEM OPERATING AT DATA SIGNALLING RATES OF UP TO 28 800 bit/s FOR USE ON THE GENERAL SWITCHED TELEPHONE NETWORK AND ON LEASED POINT-TO-POINT 2-WIRE TELEPHONE-TYPE CIRCUITS

(Geneva, 1994)

1 Scope

This modem is intended for use on connections on general switched telephone networks (GSTNs) and on point-to-point 2-wire leased telephone-type circuits. The principal characteristics of the modem are as follows:

a) duplex and half-duplex modes of operation on GSTN and point-to-point 2-wire leased circuits;

b) channel separation by echo cancellation techniques;

c) quadrature amplitude modulation (QAM) for each channel with synchronous line transmission at selectable symbol rates including the mandatory rates of 2400, 3000, and 3200 symbols/s and the optional rates of 2743, 2800, and 3429 symbols/s;

d) synchronous primary channel data signalling rates of:

- 28 800 bit/s;
- 26 400 bit/s;
- 24 000 bit/s;
- 21 600 bit/s;
- 19 200 bit/s;
- 16 800 bit/s;
- 14 400 bit/s;
- 12 000 bit/s;
- 9600 bit/s;
- 7200 bit/s;
- 4800 bit/s;
- 2400 bit/s;

e) trellis coding for all data signalling rates;

f) an optional auxiliary channel with a synchronous data signalling rate of 200 bit/s, a portion of which may be provided to the user as an asynchronous secondary channel;

g) adaptive techniques that enable the modem to achieve close to the maximum data signalling rate the channel can support on each connection;

h) exchange of rate sequences during start-up to establish the data signalling rate;

i) automoding to V-Series modems supported by V.32 *bis* Automode procedures and Group 3 facsimile machines.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other referenced Standards are subject to revision; all users of this Recommendation are therefore

encouraged to investigate the possibility of applying the most recent editions of the Recommendations and other references listed below. A list of currently valid ITU-T Recommendations is regularly published.

- ISO 2110:1989, *Information technology – Data communications – 25-pole DTE/DCE interface connector and contact number assignments.*
- ISO/IEC 11569:1993, *Information technology – Telecommunications and information exchange between systems – 26-pole interface connector mateability and contact number assignments.*
- ITU-T (CCITT) Recommendation T.30 (1988) (Amended, March 1991), *Procedures for document facsimile transmission in the general switched telephone network.*
- ITU-T Recommendation V.8 (1994), *Procedures for starting and ending sessions of data transmission over the general switched telephone network.*
- ITU-T (CCITT) Recommendation V.10 (1993), *Electrical characteristics for unbalanced double-current interchange circuits operating at data signalling rates nominally up to 100 kbit/s.*
- ITU-T (CCITT) Recommendation V.11 (1993), *Electrical characteristics for balanced double-current interchange circuits operating at data signalling rates up to 100 kbit/s.*
- ITU-T (CCITT) Recommendation V.14 (1988), *Transmission of start-stop characters over synchronous bearer channels.*
- ITU-T (CCITT) Recommendation V.21 (1988), *300 bit per second duplex modem standardized for use in the general switched telephone network.*
- ITU-T (CCITT) Recommendation V.24 (1988), *List of definitions for interchange circuits between data terminal equipment (DTE) and data circuit-terminating equipment (DCE).*
- ITU-T (CCITT) Recommendation V.25 (1984), *Automatic answering equipment and/or parallel automatic calling equipment on the general switched telephone network including procedures for disabling of echo control devices for both manually and automatically established calls.*
- ITU-T (CCITT) Recommendation V.28 (1993), *Electrical characteristics for unbalanced double-current interchange circuits.*
- ITU-T (CCITT) Recommendation V.32 (1988), *A family of 2-wire, duplex modems operating at data signalling rates of up to 9600 bit/s for use on the general switched telephone network and on leased telephone-type circuits.*
- ITU-T (CCITT) Recommendation V.32 *bis* (1991), *A duplex modem operating at data signalling rates of up to 14 400 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits.*
- ITU-T (CCITT) Recommendation V.42 (1993), *Error-correcting procedures for DCEs using asynchronous-to-synchronous conversion.*
- ITU-T (CCITT) Recommendation V.54 (1988), *Loop test devices for modems.*

3 Definitions

For the purposes of this Recommendation, the following definitions apply:

auxiliary channel: A 200 bit/s data channel which, along with the primary channel, is multiplexed into the bit stream transmitted by the modem. Data conveyed in the auxiliary channel is independent from the primary channel and may consist of secondary channel data and modem control data.

constellation shaping: A method for improving noise immunity by introducing a non-uniform two-dimensional probability distribution for transmitted signal points. The degree of constellation shaping is a function of the amount of constellation expansion.

data mode modulation parameters: Parameters determined during start-up and used during data mode transmission.

frame switching: A method for sending a fractional number of bits per mapping frame, on average, by alternating between sending an integer b – 1 bits per mapping frame and b bits per mapping frame according to a periodic switching pattern.

line probing: A method for determining channel characteristics by sending periodic signals, which are analysed by the modem and used to determine data mode modulation parameters.

nominal transmit power: Reference transmit power that is configured by the user. A modem that has negotiated a transmit power reduction in Phase 2 of the start-up procedures is said to be transmitting below the Nominal Transmit Power.

non-linear encoding: A method for improving distortion immunity near the perimeter of a signal constellation by introducing a non-uniform two-dimensional (2D) signal point spacing.

precoding: A non-linear equalization method for reducing equalizer noise enhancement caused by amplitude distortion. Equalization is performed at the transmitter using precoding coefficients provided by the remote modem.

pre-emphasis: A linear equalization method where the transmit signal spectrum is shaped to compensate for amplitude distortion. The pre-emphasis filter is selected using a filter index provided by the remote modem.

primary channel: The main data channel which, together with auxiliary channel data, constitutes the bit stream transmitted by the modem.

recipient modem: The modem which receives primary channel data in half-duplex mode.

secondary channel: A portion of the auxiliary channel that is made available to the user.

shell mapping: A method for mapping data bits to signal points in a multi-dimensional signal constellation, which involves partitioning a two-dimensional signal constellation into rings containing an equal number of points.

source modem: The modem which transmits primary channel data in half-duplex mode.

trellis encoding: A method for improving noise immunity using a convolutional coder to select a sequence of subsets in a partitioned signal constellation. The trellis encoders used in this Recommendation are all four-dimensional (4D) and they are used in a feedback structure where the inputs to the trellis encoder are derived from the signal points.

4 Abbreviations

For the purposes of this Recommendation, the following abbreviations are used:

abs[ ]	Absolute value
AMP	Auxiliary Channel Multiplexing Pattern
CCITT	International Telephone and Telegraph Consultative Committee
CME	Circuit Multiplication Equipment
CRC	Cyclic Redundancy Check
DCE	Data Circuit Terminating Equipment
DPSK	Differential Phase Shift Keying
DTE	Data Terminal Equipment
GPA	Generating Polynomial – Answer modem
GPC	Generating Polynomial – Call modem
GSTN	General Switched Telephone Network
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
ITU-T	International Telecommunications Union – Telecommunications Standardization Sector
LSB	Least Significant Bit
MSB	Most Significant Bit
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RTDEa	Round-Trip Delay Estimate – Answer modem
RTDEc	Round-Trip Delay Estimate – Call modem
SWP	Switching Pattern

5 Line Signals

5.1 Data Signalling Rates

The primary channel shall support synchronous data signalling rates of 2400 bit/s to 28 800 bit/s in multiples of 2400 bit/s. An auxiliary channel with a synchronous data signalling rate of 200 bit/s may also be optionally supported. The primary and auxiliary data signalling rates shall be determined during Phase 4 of modem start-up according to the procedures described in 11.4. or 12.4. The auxiliary channel shall be used only when the call and answer modems have both declared this capability. The primary channel data signalling rates can be asymmetric.

5.2 Symbol Rates

The symbol rate shall be $S = (a/c) \cdot 2400 \pm 0.01\%$ two-dimensional (2D) symbols per second, where a and c are integers from the set specified in Table 1 (in which symbol rates are shown rounded to the nearest integer). The symbol rates 2400, 3000, and 3200 are mandatory; 2743, 2800, and 3429 are optional. The symbol rate shall be selected during Phase 2 of modem start-up according to the procedures described in 11.2 or 12.2. Asymmetric symbol rates are optionally supported and shall be used only when the call and answer modems have both declared this capability.

TABLE 1/V.34

Symbol rates

Symbol Rate, S	a	c
2400	1	1
2743	8	7
2800	7	6
3000	5	4
3200	4	3
3429	10	7

5.3 Carrier Frequencies

The carrier frequency shall be $(d/e) \cdot S$ Hz, where d and e are integers. One of two carrier frequencies can be selected at each symbol rate, as specified in Table 2, which gives the values of d and e and the corresponding frequencies rounded to the nearest integer. The carrier frequency shall be determined during Phase 2 of modem start-up according to the procedures specified in 11.2 or 12.2. Asymmetric carrier frequencies shall be supported.

TABLE 2/V.34

Carrier frequencies versus symbol rate

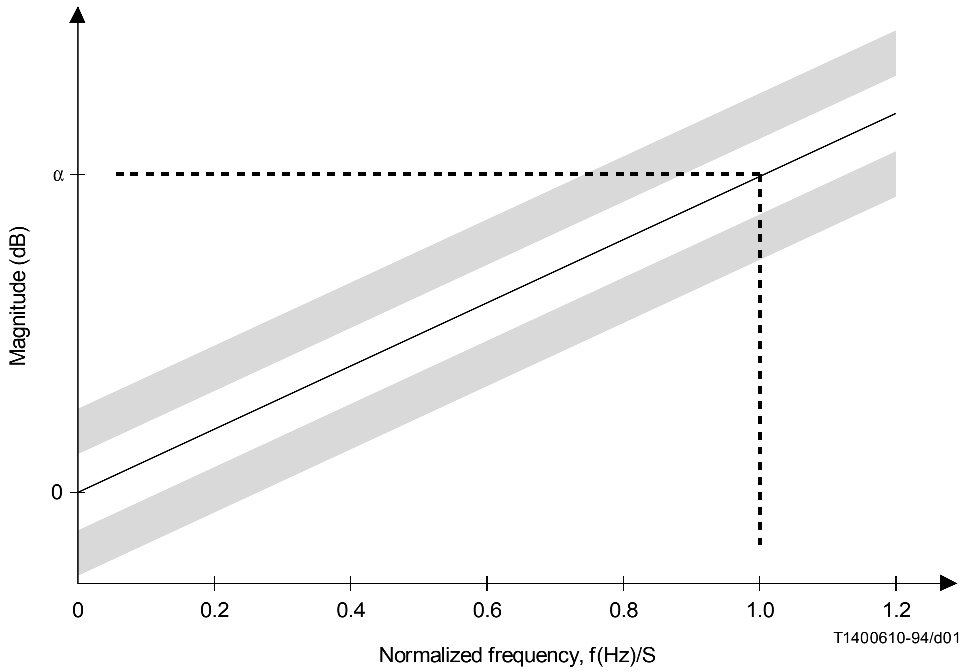
	Low Carrier			High Carrier		
Symbol Rate, S	Frequency	d	e	Frequency	d	e
2400	1600	2	3	1800	3	4
2743	1646	3	5	1829	2	3
2800	1680	3	5	1867	2	3
3000	1800	3	5	2000	2	3
3200	1829	4	7	1920	3	5
3429	1959	4	7	1959	4	7

5.4 Pre-emphasis

5.4.1 Transmit Spectrum Specifications

The transmit spectrum specifications use a normalized frequency, which is defined as the ratio f/S, where f is the frequency in Hz and S is the symbol rate.

The magnitude of the transmitted spectrum shall conform to the templates shown in Figures 1 and 2 for normalized frequencies in the range from (d/e – 0.45) to (d/e + 0.45). The transmitted spectrum shall be measured using a 600 Ω pure resistive load.



NOTE – Tolerance for transmit spectrum is ± 1 dB.

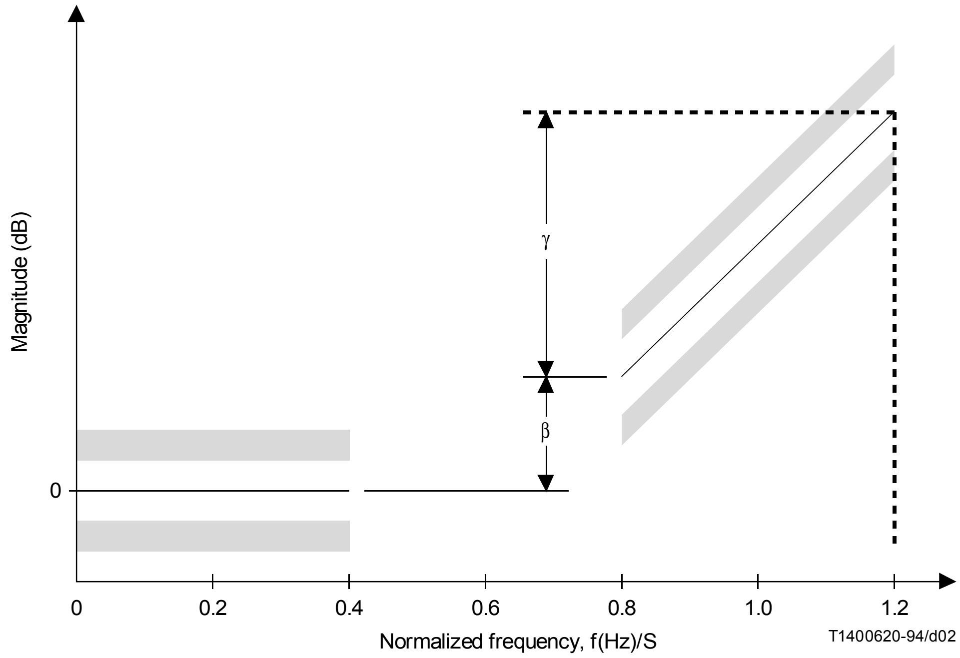
FIGURE 1/V.34

Transmit spectra templates for indices 0 to 5

TABLE 3/V.34

Parameter α for indices 0 to 5

Index	α
0	0 dB
1	2 dB
2	4 dB
3	6 dB
4	8 dB
5	10 dB



NOTE – Over the range specified, the tolerance for the transmit spectrum magnitude is ± 1 dB.

FIGURE 2/V.34

Transmit spectra templates for indices 6 to 10

TABLE 4/V.34

Parameters β and γ for indices 6 to 10

Index	β	γ
6	0.5 dB	1.0 dB
7	1.0 dB	2.0 dB
8	1.5 dB	3.0 dB
9	2.0 dB	4.0 dB
10	2.5 dB	5.0 dB

5.4.2 Selection Method

The transmitted spectrum shall be specified by a numerical index. The index shall be provided by the remote modem during Phase 2 of start-up by the procedures defined in 11.2. or 12.2.

6 DTE Interfaces

Where external physical interfaces for the interchange circuits are not present, the equivalent functionality of the circuits must still be provided (see Table 5).

TABLE 5/V.34

Interchange circuits for combined primary and secondary channel interfaces

Interchange Circuit No.	Interchange Circuit Description	NOTES
102 103 104 105 106	Signal ground or common return Transmitted data Received data Request to send Ready for sending	
107 108/1 or 108/2 109	Data set ready Connect data set to line Data terminal ready Data channel received line signal detector	
113 114 115 125 133 140 141 142	Transmitter signal element timing (DTE source) Transmitter signal element timing (DCE source) Receiver signal element timing (DCE source) Calling indicator Ready for receiving Loopback/maintenance Local loopback Test indicator	1 2 2 3
118 119 120 121 122	Transmitted secondary channel data Received secondary channel data Transmit secondary channel line signal Secondary channel ready Secondary channel received line signal detector	4 4 4, 5 4, 5 4, 5, 6

NOTES

1 When the modem is not operating in a synchronous mode at the interface, any signals on this circuit shall be disregarded. Many DTEs operating in an asynchronous mode do not have a generator connected to this circuit.

2 When the modem is not operating in a synchronous mode at the interface, this circuit shall be clamped to the OFF condition. Many DTEs operating in an asynchronous mode do not terminate this circuit.

3 Operation of circuit 133 shall be in accordance with 7.3.1/V.42.

4 This circuit is provided where the optional secondary channel is implemented without a separate interface.

5 This circuit need only be provided where required by the application.

6 This circuit is in the ON condition if circuit 109 is in the ON condition *and* the optional secondary channel is enabled.

Where a separate interface is provided for the optional secondary channel, interchange circuits as specified in Table 6 shall be provided.

6.1 Synchronous Interfacing (Primary Channel Only)

The modems shall accept synchronous data from the DTE on circuit 103 (see Recommendation V.24) under control of circuit 113 or 114. The modem shall pass synchronous data to the DTE on circuit 104 under control of circuit 115. The modem shall provide to the DTE a clock on circuit 114 for transmit-data timing, and a clock on circuit 115 for receive-data timing. The transmit-data timing may, however, originate in the DTE and be transferred to the modem via circuit 113. In some applications, it may be necessary to synchronize the transmitter timing to the receiver timing inside the modem.

After the start-up and retrain sequences, circuit 106 must follow the state of circuit 105 within 2 ms.

OFF to ON and ON to OFF transitions of circuit 109 shall occur solely in accordance with the operating sequences defined in clauses 11 and 12.

TABLE 6/V.34

Interchange circuits for a separate secondary channel interface

Interchange Circuit		NOTES
No.	Description	
102 103 104 105 106	Signal ground or common return Transmitted data Received data Request to send Ready for sending	 1
107 108/2 109	Data set ready Data terminal ready Data channel received line signal detector	1, 2 1 1, 2

NOTES

1 This circuit need only be provided where required by the application.

2 This circuit is in the ON condition if the corresponding interchange circuit of the primary channel is in the ON condition *and* the optional secondary channel is enabled.

6.2 Asynchronous Character-mode Interfacing

6.2.1 Primary Channel

The modem may include an asynchronous-to-synchronous converter interfacing to the DTE in an asynchronous (or start-stop character) mode. The protocol for the conversion shall be in accordance with Recommendation V.14 or V.42. Data compression may also be employed.

6.2.2 Secondary Channel

The secondary channel is for asynchronous mode only. However, since the modulation process operates synchronously, an asynchronous-to-synchronous conversion combined with a data flow control shall be provided, as specified in 6.2.2.1.

6.2.2.1 DTE-to-DCE Flow Control on the Secondary Channel Interface

The modem shall indicate to the secondary channel DTE a temporary inability to accept data on either circuit 103 or 118 (DCE-not-ready condition). Upon receiving such an indication, the DTE should complete transmission of any partially transmitted character and then cease transmitting data on circuit 103 (118) and clamp circuit 103 (118) to binary 1. When the DCE-not-ready condition is cleared, the DTE may resume the transmission of data on circuit 103 (118). The flow control indication may be performed in one of two ways:

a) *Using circuit 106 (121)* – A DCE-not-ready condition may be indicated by turning circuit 106 (121) OFF and cleared by turning circuit 106 (121) ON.

b) *Using DC1/DC3 characters (XON/XOFF functions)* – A DCE-not-ready condition may be indicated by transmitting a DC3 character and cleared by transmitting a DC1 character on circuit 104 (119).

Both techniques a) and b) shall be provided. The choice of technique is a user-configurable option.

The response time of the DTE to an indication of a DCE-not-ready condition is for further study. This time should be kept as short as possible. DCEs shall accommodate latency in the DTE recognition of the DCE-not-ready indication by accepting additional characters on circuit 103 (118) after the indication is given.

If a break signal is the next item to be delivered across the DTE/DCE interface, it shall be delivered regardless of the flow control state. In the case of a non-expedited/non-destructive break, data to be delivered prior to the break remains subject to flow control.

NOTES

1 No DCE-to-DTE flow control is provided on the secondary channel.

2 The alternative use of the asynchronous-to-synchronous conversion in accordance with Recommendation V.14 is still under consideration; in this case, DTE-to-DCE flow control may be optional.

6.3 Half-duplex Mode Interfacing

Where the modem is operating in the half-duplex mode, the primary channel and control channel share the primary channel interchange circuits given in Table 5. The mechanism for allocation of data to the primary or control channel is beyond the scope of this Recommendation.

6.4 Electrical Characteristics of Interchange Circuits

6.4.1 Primary Channel

Where an external physical interface is provided, electrical characteristics conforming to Recommendations V.10 and V.11 shall be used. The connector and pole assignments specified by ISO 2110 Amd. 1.0 or ISO/IEC 11569, column "V-Series > 20 000 bit/s", shall be used. Alternatively, when the DTE-DCE interface speed is not designed to exceed 116 kbit/s, these same connectors may be used with characteristics conforming to Recommendation V.10 only (see Note).

NOTE – In this case ISO is presently considering assigning the same pole assignments in ISO 2110 and ISO/IEC 11569 as those presently assigned for interfaces using Recommendation V.28 electrical characteristics under the heading "V-Series < 20 000 bit/s".

6.4.2 Secondary Channel

Where an external physical interface is provided for the secondary channel, electrical characteristics in accordance with Recommendation V.10 shall be used (see Note under 6.4.1).

6.5 Fault Condition on Interchange Circuits

The DCE shall interpret a fault condition on circuits 105, 108 and 120 (where provided) as an OFF condition using failure detection type 1.

All other circuits not referred to may use failure detection type 0 or 1.

NOTES

1 The DTE interprets a fault condition on circuit 107 as an OFF condition using failure detection type 1.

2 See clause 10/V.10 for the definition of failure detection types.

6.6 Thresholds and Response Times of Circuit 109

6.6.1 Duplex Mode

Thresholds and response times are not applicable in duplex mode because a line signal detector cannot be expected to distinguish wanted received signals from unwanted talker echoes.

6.6.2 Half-Duplex Mode

Circuit 109 shall turn OFF 20 to 25 ms after the level of the received signal appearing at the line terminals of the modem falls below the relevant threshold defined as follows:

Greater than –43 dBm: circuit 109 ON

Less than –48 dBm: circuit 109 OFF

The condition of circuit 109 between the ON and OFF levels is not specified except that the signal detector shall provide hysteresis, such that the level at which the OFF to ON transition occurs shall be at least 2 dB greater than that for the ON to OFF transition.

7 Scrambler

A self-synchronizing scrambler shall be included in the modem for the primary channel data. Auxiliary channel data is not scrambled. Each transmission direction uses a different scrambler. According to the direction of transmission, the generating polynomial is:

Call mode modem generating polynomial: $(GPC) = 1 + x^{-18} + x^{-23}$ (7-1/V.34)

or

Answer mode modem generating polynomial: $(GPA) = 1 + x^{-5} + x^{-23}$ (7-2/V.34)

At the transmitter, the scrambler shall effectively divide the primary channel data sequence by the generating polynomial. The coefficients of the quotients of this division, taken in descending order, form the data sequence which shall appear at the output of the scrambler.

8 Framing

8.1 Overview

Figure 3 provides an overview of the frame structure.

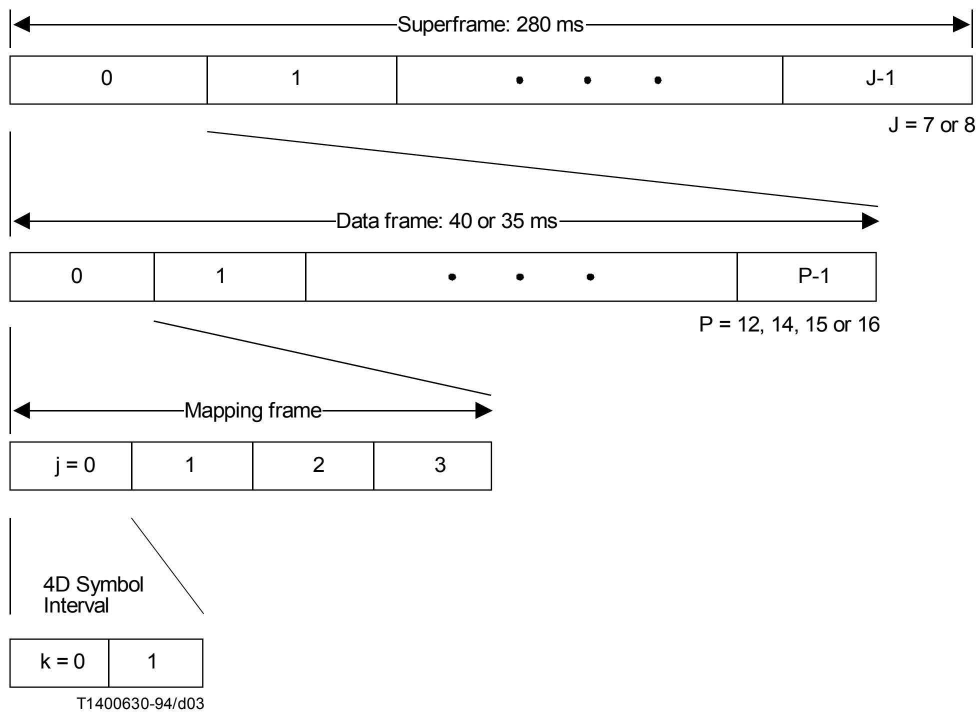


FIGURE 3/V.34

Overview of framing and indexing

The duration of a superframe is 280 ms. A superframe shall consist of J data frames, where J = 7 at symbol rates 2400, 2800, 3000, and 3200, and J = 8 at symbol rates 2743 and 3429. A data frame shall consist of P mapping frames, where P is specified in Table 7. A mapping frame shall consist of four four-dimensional (4D) symbol intervals. A 4D symbol interval shall consist of two 2D symbol intervals. A bit inversion method shall be used for superframe synchronization (see 9.6.3).

TABLE 7/V.34

Framing parameters

Symbol Rate, S	J	P
2400	7	12
2743	8	12
2800	7	14
3000	7	15
3200	7	16
3429	8	15

Mapping frames are indicated by the time index i, where i = 0 for the first mapping frame of signal B1 defined in 10.1.3.1, and is incremented by 1 for each mapping frame thereafter. 4D symbol intervals are indicated by the time index m = 4i + j, where j (= 0, 1, 2, 3) is a cyclic time index that indicates the position of the 4D symbol interval in a mapping frame. 2D symbol intervals are indicated by the time index n = 2m + k, where k (= 0, 1) is a cyclic time index that indicates the position of the 2D symbol interval in a 4D symbol interval.

8.2 Mapping Frame Switching

An integer number of data bits shall be transmitted in every data frame. The total number of primary and auxiliary channel data bits transmitted in a data frame is denoted by:

$$N = R \cdot 0.28/J \qquad (8\text{-}1/V.34)$$

where R is the sum of the primary channel data signalling rate and the auxiliary channel data signalling rate.

The total number of (primary and auxiliary channel) data bits transmitted in a mapping frame shall vary between b – 1 (“low frame”) and b (“high frame”) bits according to a periodic switching pattern SWP, of period P, such that the average number of data bits per mapping frame is N/P. The value of b is defined as the smallest integer not less than N/P. The number of high frames in a period is the remainder

$$r = N - (b - 1)P \qquad (8\text{-}2/V.34)$$

where $1 \leq r \leq P$

SWP is represented by 12 to 16-bit binary numbers where 0 and 1 represent low and high frames, respectively. The left-most bit corresponds to the first mapping frame in a data frame. The right-most bit is always 1.

SWP may be derived using an algorithm which uses a counter as follows: Prior to each data frame the counter is set to zero. The counter is incremented by r at the beginning of each mapping frame. If the counter is less than P, send a low frame; otherwise, send a high frame and decrement the counter by P.

Table 8 gives the values for b and SWP for all combinations of data rate and symbol rate. In Table 8, SWP is represented as a hexadecimal number. For example, at 19 200 bit/s and symbol rate 3000, SWP is 0421 (hex) or 000 0100 0010 0001 (binary).

8.3 Multiplexing of Primary and Auxiliary Channel Bits

The auxiliary channel bits shall be time-division multiplexed with the scrambled primary channel bits.

The number of auxiliary channel bits transmitted per data frame is W = 8 at symbol rates 2400, 2800, 3000, and 3200, and W = 7 at symbol rates 2743 and 3429. In each mapping frame, the bit $I1_{i,0}$ is used to send either an auxiliary channel bit or a primary channel bit according to the auxiliary channel multiplexing pattern, AMP, of period P (see Figure 4). AMP can be represented as a P-bit binary number where a 1 indicates that an auxiliary channel bit is sent and a 0 indicates that a primary channel bit is sent. AMP depends only upon the symbol rate and is given in Table 9 as a hexadecimal number. The left-most bit corresponds to the first mapping frame in a data frame.

TABLE 8/V.34

[b, Switching Pattern (SWP)] as a function of data rate and symbol rate

Data Rate, R	2400 sym/s		2743 sym/s		2800 sym/s		3000 sym/s		3200 sym/s		3429 sym/s	
	P = 12		P = 12		P = 14		P = 15		P = 16		P = 15	
	b	SWP	b	SWP	b	SWP	b	SWP	b	SWP	b	SWP
2400	8	FFF	–	–	–	–	–	–	–	–	–	–
2600	9	6DB	–	–	–	–	–	–	–	–	–	–
4800	16	FFF	14	FFF	14	1BB7	13	3DEF	12	FFFF	12	0421
5000	17	6DB	15	56B	15	0489	14	1249	13	5555	12	36DB
7200	24	FFF	21	FFF	21	15AB	20	0421	18	FFFF	17	3DEF
7400	25	6DB	22	56B	22	0081	20	3777	19	5555	18	0889
9600	32	FFF	28	FFF	28	0A95	26	2D6B	24	FFFF	23	14A5
9800	33	6DB	29	56B	28	3FFF	27	0081	25	5555	23	3F7F
12 000	40	FFF	35	FFF	35	0489	32	7FFF	30	FFFF	28	7FFF
12 200	41	6DB	36	56B	35	1FBF	33	2AAB	31	5555	29	1555
14 400	48	FFF	42	FFF	42	0081	39	14A5	36	FFFF	34	2D6B
14 600	49	6DB	43	56B	42	1BB7	39	3FFF	37	5555	35	0001
16 800	56	FFF	49	FFF	48	3FFF	45	3DEF	42	FFFF	40	0421
17 000	57	6DB	50	56B	49	15AB	46	1249	43	5555	40	36DB
19 200	64	FFF	56	FFF	55	1FBF	52	0421	48	FFFF	45	3DEF
19 400	65	6DB	57	56B	56	0A95	52	3777	49	5555	46	0889
21 600	72	FFF	63	FFF	62	1BB7	58	2D6B	54	FFFF	51	14A5
21 800	73	6DB	64	56B	63	0489	59	0081	55	5555	51	3F7F
24 000	–	–	70	FFF	69	15AB	64	7FFF	60	FFFF	56	7FFF
24 200	–	–	71	56B	70	0081	65	2AAB	61	5555	57	1555
26 400	–	–	–	–	–	–	71	14A5	66	FFFF	62	2D6B
26 600	–	–	–	–	–	–	71	3FFF	67	5555	63	0001
28 800	–	–	–	–	–	–	–	–	72	FFFF	68	0421
29 000	–	–	–	–	–	–	–	–	73	5555	68	36DB

The auxiliary channel multiplexing pattern may be derived using an algorithm similar to the algorithm for SWP, the frame switching pattern. Prior to each data frame, a counter is set to zero. The counter is incremented by W at the beginning of each mapping frame. If the counter is less than P, a primary channel bit is sent; otherwise, an auxiliary channel bit is sent, and the counter is decremented by P.

TABLE 9/V.34

Auxiliary channel multiplexing parameters

Symbol Rate, S	W	P	AMP
2400	8	12	6DB
2743	7	12	56B
2800	8	14	15AB
3000	8	15	2AAB
3200	8	16	5555
3429	7	15	1555

9 Encoder

The block diagram in Figure 4 is an overview of the encoder.

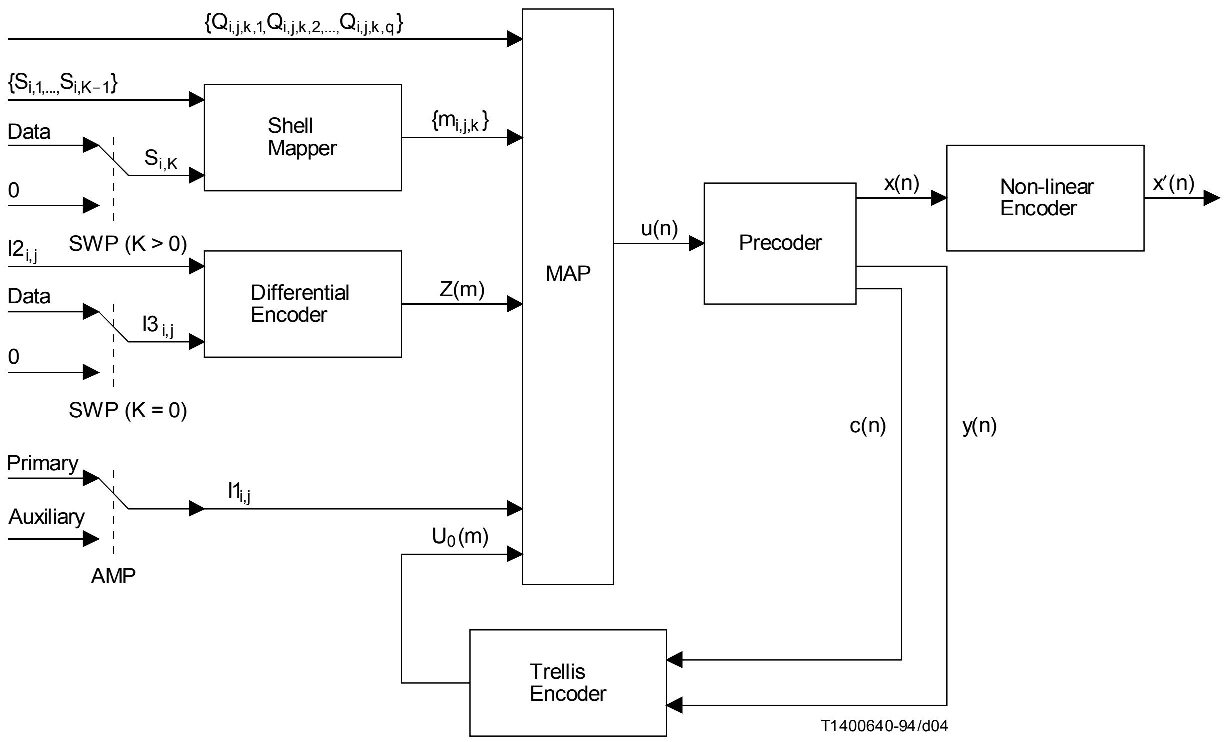


FIGURE 4/V.34

Encoder block diagram

9.1 Signal Constellations

Signal constellations consist of complex-valued signal points which lie on a two-dimensional rectangular grid.

All signal constellations used in this Recommendation are subsets of a 960-point superconstellation. Figure 5 shows one-quarter of the points in the superconstellation. These points are labelled with decimal integers between 0 and 239. The point with the smallest magnitude is labelled as 0, the point with the next larger magnitude is labelled as 1, and so on. When two or more points have the same magnitude, the point with the greatest imaginary component is taken first. The full superconstellation is the union of the four quarter-constellations obtained by rotating the constellation in Figure 5 by 0, 90, 180, and 270 degrees.

A signal constellation with L points consists of the L/4 points from the quarter-constellation in Figure 5 with labels 0 through L/4 – 1, and the 3L/4 points which are obtained by 90, 180 and 270 degree rotations of these signal points.

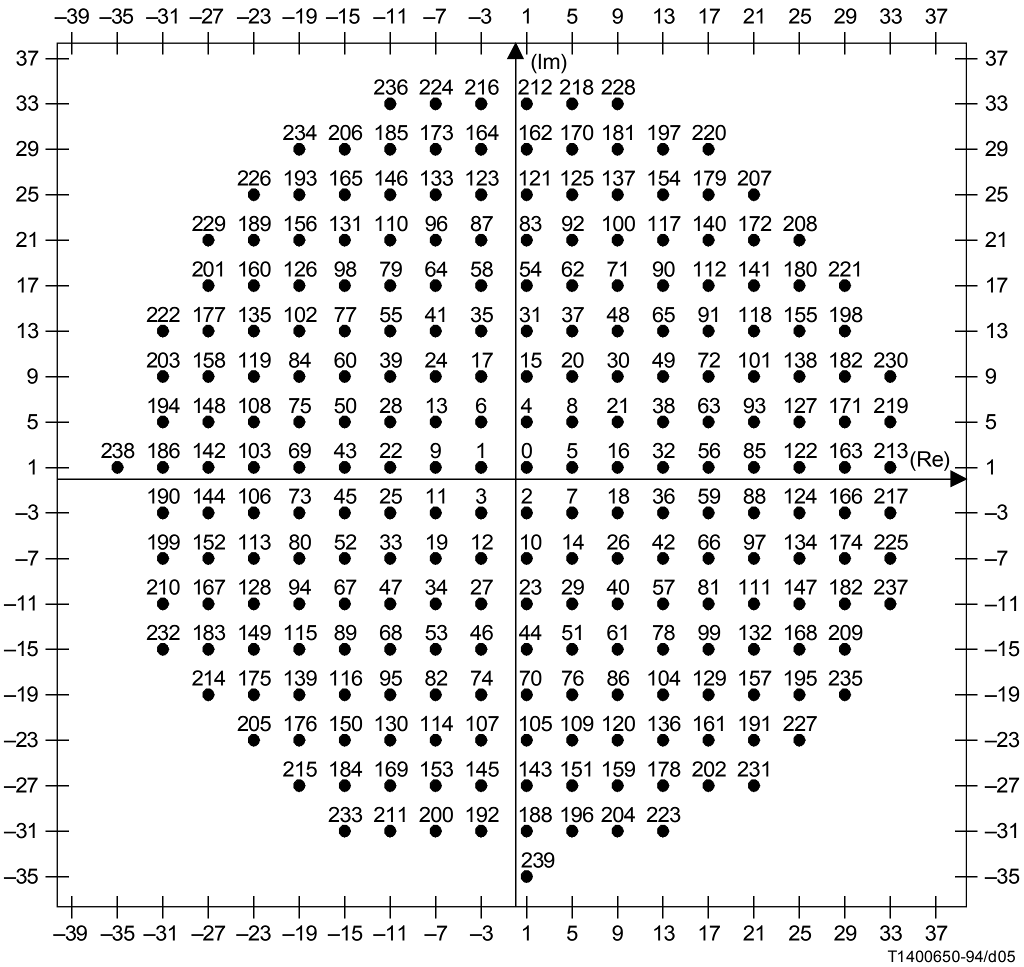


FIGURE 5/V.34

One-quarter of the points in the superconstellation

9.2 Mapping Parameters

The number of bits put into the shell mapper per mapping frame is denoted by K where $0 \leq K < 32$. The values of K are given in Table 10. K can also be determined from b as follows:

$$
\begin{aligned}
K &= 0 && \text{if } b \leq 12 \\
&= b - 12 - 8q && \text{if } b > 12
\end{aligned}
\qquad (9\text{-}1/V.34)
$$

where q is the smallest non-negative integer such that $K < 32$ ($q = 0$ when $K = 0$).

The 2D signal constellation is partitioned into M concentric rings of equal size. For each data rate and symbol rate, two possible values of M are allowed: a "minimum" value which minimizes the number of points in the 2D signal constellation, and a larger value which allows the achievement of shaping gain. M is selected during Phase 4 of the start-up procedures as described in 11.4 or 12.4.

The values of M are given in Table 10. These values can also be calculated from K as follows: the minimum value of M is the smallest integer no less than $2^{K/8}$ and the larger value of M is the nearest integer to $1.25 \cdot 2^{K/8}$ (not less than the minimum value of M).

Table 10 gives the number of signal points L in the 2D signal constellation. L can also be calculated according to:

$$L = 4M \cdot 2^q \qquad (9\text{-}2/V.34)$$

TABLE 10/V.34

Mapping parameters K, M and L at different data rates and symbol rates

Symbol Rate, S	Data Rate, R	K	M		L	
			Minimum	Expanded	Minimum	Expanded
2400	2400	0	1	1	4	4
	2600	0	1	1	4	4
	4800	4	2	2	8	8
	5000	5	2	2	8	8
	7200	12	3	4	12	16
	7400	13	4	4	16	16
	9600	20	6	7	24	28
	9800	21	7	8	28	32
	12 000	28	12	14	48	56
	12 200	29	13	15	52	60
	14 400	28	12	14	96	112
	14 600	29	13	15	104	120
	16 800	28	12	14	192	224
	17 000	29	13	15	208	240
	19 200	28	12	14	384	448
	19 400	29	13	15	416	480
	21 600	28	12	14	768	896
	21 800	29	13	15	832	960
2743	4800	2	2	2	8	8
	5000	3	2	2	8	8
	7200	9	3	3	12	12
	7400	10	3	3	12	12
	9600	16	4	5	16	20
	9800	17	5	5	20	20
	12 000	23	8	9	32	36
	12 200	24	8	10	32	40
	14 400	30	14	17	56	68
	14 600	31	15	18	60	72
	16 800	29	13	15	104	120
	17 000	30	14	17	112	136
	19 200	28	12	14	192	224
	19 400	29	13	15	208	240
	21 600	27	11	13	352	416
	21 800	28	12	14	384	448
	24 000	26	10	12	640	768
	24 200	27	11	13	704	832

TABLE 10/V.34 *(continued)*

Mapping parameters K, M and L at different data rates and symbol rates

Symbol Rate, S	Data Rate, R	K	M		L	
			Minimum	Expanded	Minimum	Expanded
2800	4800	2	2	2	8	8
	5000	3	2	2	8	8
	7200	9	3	3	12	12
	7400	10	3	3	12	12
	9600	16	4	5	16	20
	9800	16	4	5	16	20
	12 000	23	8	9	32	36
	12 200	23	8	9	32	36
	14 400	30	14	17	56	68
	14 600	30	14	17	56	68
	16 800	28	12	14	96	112
	17 000	29	13	15	104	120
	19 200	27	11	13	176	208
	19 400	28	12	14	192	224
	21 600	26	10	12	320	384
	21 800	27	11	13	352	416
	24 000	25	9	11	576	704
	24 200	26	10	12	640	768
3000	4800	1	2	2	8	8
	5000	2	2	2	8	8
	7200	8	2	3	8	12
	7400	8	2	3	8	12
	9600	14	4	4	16	16
	9800	15	4	5	16	20
	12 000	20	6	7	24	28
	12 200	21	7	8	28	32
	14 400	27	11	13	44	52
	14 600	27	11	13	44	52
	16 800	25	9	11	72	88
	17 000	26	10	12	80	96
	19 200	24	8	10	128	160
	19 400	24	8	10	128	160
	21 600	30	14	17	224	272
	21 800	31	15	18	240	288
	24 000	28	12	14	384	448
	24 200	29	13	15	416	480
	26 400	27	11	13	704	832
	26 600	27	11	13	704	832

TABLE 10/V.34 *(end)*

Mapping parameters K, M and L at different data rates and symbol rates

Symbol Rate, S	Data Rate, R	K	M		L	
			Minimum	Expanded	Minimum	Expanded
3200	4800	0	1	1	4	4
	5000	1	2	2	8	8
	7200	6	2	2	8	8
	7400	7	2	2	8	8
	9600	12	3	4	12	16
	9800	13	4	4	16	16
	12 000	18	5	6	20	24
	12 200	19	6	6	24	24
	14 400	24	8	10	32	40
	14 600	25	9	11	36	44
	16 800	30	14	17	56	68
	17 000	31	15	18	60	72
	19 200	28	12	14	96	112
	19 400	29	13	15	104	120
	21 600	26	10	12	160	192
	21 800	27	11	13	176	208
	24 000	24	8	10	256	320
	24 200	25	9	11	288	352
	26 400	30	14	17	448	544
	26 600	31	15	18	480	576
	28 800	28	12	14	768	896
	29 000	29	13	15	832	960
3429	4800	0	1	1	4	4
	5000	0	1	1	4	4
	7200	5	2	2	8	8
	7400	6	2	2	8	8
	9600	11	3	3	12	12
	9800	11	3	3	12	12
	12 000	16	4	5	16	20
	12 200	17	5	5	20	20
	14 400	22	7	8	28	32
	14 600	23	8	9	32	36
	16 800	28	12	14	48	56
	17 000	28	12	14	48	56
	19 200	25	9	11	72	88
	19 400	26	10	12	80	96
	21 600	31	15	18	120	144
	21 800	31	15	18	120	144
	24 000	28	12	14	192	224
	24 200	29	13	15	208	240
	26 400	26	10	12	320	384
	26 600	27	11	13	352	416
	28 800	24	8	10	512	640
	29 000	24	8	10	512	640

9.3 Parser

9.3.1 Procedure for b > 12

In high mapping frames (b bits), the first K scrambled primary channel data bits are put into the shell mapper, where the values of K are given in Table 10. In low mapping frames (b – 1 bits), a zero bit is inserted after the first K – 1 bits, and the resulting K bits are then put into the shell mapper.

The first K scrambled data bits in mapping frame i are denoted by $(S_{i,1}, S_{i,2}, ..., S_{i,K})$. In low frames, $S_{i,K} = 0$.

In each mapping frame the remaining b – K bits are divided into four groups of equal size, corresponding to four 4D symbols. The first three bits in each group are denoted by $(I1_{i,j,}, I2_{i,j,}, I3_{i,j,})$, $0 \le j \le 3$. (When the auxiliary channel is present, the bit $I1_{i,0}$ in the first group is either a primary channel bit or an auxiliary channel bit depending on AMP, the Auxiliary Channel Multiplexing Pattern, as explained in 8.3.) The remaining $2q = (b – K)/4 – 3$ bits are divided into two subgroups of size q denoted by $(Q_{i,j,k,1}, Q_{i,j,k,2}, ..., Q_{i,j,k,q})$, $0 \le k \le 1$, corresponding to two 2D symbols. Thus, mapping frame i consists of the following sequence of bits:

$(S_{i,1}, S_{i,2}, ..., S_{i,K})$,
$(I1_{i,0}, I2_{i,0}, I3_{i,0}), (Q_{i,0,0,1}, Q_{i,0,0,2}, ..., Q_{i,0,0,q}), (Q_{i,0,1,1}, Q_{i,0,1,2}, ..., Q_{i,0,1,q})$,
$(I1_{i,1}, I2_{i,1}, I3_{i,1}), (Q_{i,1,0,1}, Q_{i,1,0,2}, ..., Q_{i,1,0,q}), (Q_{i,1,1,1}, Q_{i,1,1,2}, ..., Q_{i,1,1,q})$,
$(I1_{i,2}, I2_{i,2}, I3_{i,2}), (Q_{i,2,0,1}, Q_{i,2,0,2}, ..., Q_{i,2,0,q}), (Q_{i,2,1,1}, Q_{i,2,1,2}, ..., Q_{i,2,1,q})$,
$(I1_{i,3}, I2_{i,3}, I3_{i,3}), (Q_{i,3,0,1}, Q_{i,3,0,2}, ..., Q_{i,3,0,q}), (Q_{i,3,1,1}, Q_{i,3,1,2}, ..., Q_{i,3,1,q})$.

NOTE – $S_{i,1}$ is the earliest bit in time, and $Q_{i,3,1,q}$ is the latest.

9.3.2 Procedure for b ≤ 12

For this case, K = 0 and the ring indices $m_{i,j,k}$ generated by the shell mapper are always zero. In each mapping frame, the b bits are divided into four groups corresponding to four 4D symbols. The bits in each group are denoted by $(I1_{i,j}, I2_{i,j}, I3_{i,j})$, $0 \le j \le$€3. (When the auxiliary channel is present, the bit $I1_{i,0}$ in the first group is either a primary channel bit or an auxiliary channel bit depending upon AMP, as explained in 8.3.) According to the switching patterns given in Table 8, 8, 9, 11 or 12 bits are transmitted per mapping frame in the following order:

8 bits per mapping frame:	$(I1_{i,0}, I2_{i,0}, 0), (I1_{i,1}, I2_{i,1}, 0), (I1_{i,2}, I2_{i,2}, 0), (I1_{i,3}, I2_{i,3}, 0)$
9 bits per mapping frame:	$(I1_{i,0}, I2_{i,0}, I3_{i,0}), (I1_{i,1}, I2_{i,1}, 0), (I1_{i,2}, I2_{i,2}, 0), (I1_{i,3}, I2_{i,3}, 0)$
11 bits per mapping frame:	$(I1_{i,0}, I2_{i,0}, I3_{i,0}), (I1_{i,1}, I2_{i,1}, I3_{i,1}), (I1_{i,2}, I2_{i,2}, I3_{i,2}), (I1_{i,3}, I2_{i,3}, 0)$
12 bits per mapping frame:	$(I1_{i,0}, I2_{i,0}, I3_{i,0}), (I1_{i,1}, I2_{i,1}, I3_{i,1}), (I1_{i,2}, I2_{i,2}, I3_{i,2}), (I1_{i,3}, I2_{i,3}, I3_{i,3})$

9.4 Shell Mapper

In every mapping frame, the shell mapper maps K input bits $(S_{i,1}, S_{i,2}, ..., S_{i,K})$ into 8 output ring indices $\{m_{i,0,0}, m_{i,0,1}, ..., m_{i,3,0}, m_{i,3,1}\}$, where $0 \le m_{i,j,K} < M$, according to the algorithm described below which specifies the mapping function between input bits and output indices. The parameters K and M are specified in 9.2.

NOTE – Other implementations are possible but the mapping function must be identical to that given in the algorithm described below.

Definitions:

$$g_2(p) = M - \text{abs}[p - M + 1] \qquad 0 \le p \le 2(M - 1)$$
$$= 0 \qquad \text{otherwise} \qquad (9\text{-}3/V.34)$$

$$g_4(p) = g_2(0)g_2(p) + g_2(1)g_2(p-1) + ... + g_2(p)g_2(0) \qquad 0 \le p \le 4(M - 1)$$
$$= 0 \qquad \text{otherwise} \qquad (9\text{-}4/V.34)$$

$$g_8(p) = g_4(0)g_4(p) + g_4(1)g_4(p-1) + ... + g_4(p)g_4(0) \qquad 0 \le p \le 8(M - 1) \qquad (9\text{-}5/V.34)$$

$$z_8(p) = g_8(0) + g_8(1) + g_8(2) + ... + g_8(p-1) \qquad 0 \le p \le 8(M - 1) \qquad (9\text{-}6/V.34)$$

Algorithm:

The algorithm shall first determine 8 integers A, B, C, D, E, F, G, H as follows:

1) Represent the K shell mapping bits by an integer R_0 defined by

$$R_0 = S_{i,1} + 2^1 \cdot S_{i,2} + 2^2 \cdot S_{i,3} + \ldots + 2^{K-1} \cdot S_{i,K} \qquad (9\text{-}7/V.34)$$

2) Find the largest integer A for which $z_8(A) \leq R_0$.

3) Determine the largest integer B such that $R_1 \geq 0$, where

$$\begin{aligned} R_1 &= R_0 - z_8(A) && \text{if } B = 0 \\ &= R_0 - z_8(A) - \sum_{p=0}^{B-1} g_4(p)g_4(A-p) && \text{if } B > 0 \end{aligned} \qquad (9\text{-}8/V.34)$$

4) Determine the integers:

$$R_2 = R_1 \text{ modulo } g_4(B), \text{ where } 0 \leq R_2 \leq g_4(B) - 1 \qquad (9\text{-}9/V.34)$$
$$R_3 = (R_1 - R_2)/g_4(B) \qquad (9\text{-}10/V.34)$$

5.1) Determine the largest integer C such that $R_4 \geq 0$, where

$$\begin{aligned} R_4 &= R_2 && \text{if } C = 0 \\ &= R_2 - \sum_{p=0}^{C-1} g_2(p)g_2(B-p) && \text{if } C > 0 \end{aligned} \qquad (9\text{-}11/V.34)$$

5.2) Determine the largest integer D such that $R_5 \geq 0$, where

$$\begin{aligned} R_5 &= R_3 && \text{if } D = 0 \\ &= R_3 - \sum_{p=0}^{D-1} g_2(p)g_2(A-B-p) && \text{if } D > 0 \end{aligned} \qquad (9\text{-}12/V.34)$$

6.1) Determine the integers:

$$E = R_4 \text{ modulo } g_2(C), \text{ where } 0 \leq E \leq g_2(C) - 1 \qquad (9\text{-}13/V.34)$$
$$F = (R_4 - E)/g_2(C) \qquad (9\text{-}14/V.34)$$

6.2) Determine the integers:

$$G = R_5 \text{ modulo } g_2(D), \text{ where } 0 \leq G \leq g_2(D) - 1 \qquad (9\text{-}15/V.34)$$
$$H = (R_5 - G)/g_2(D) \qquad (9\text{-}16/V.34)$$

The ring indices are determined from the integers A, B, C, D, E, F, G, H as follows:

- If $C < M$, then $m_{i,0,0} = E$ and $m_{i,0,1} = C - m_{i,0,0}$ (9-17/V.34)
- If $C \geq M$, then $m_{i,0,1} = M - 1 - E$ and $m_{i,0,0} = C - m_{i,0,1}$ (9-18/V.34)

- If $B - C < M$, then $m_{i,1,0} = F$ and $m_{i,1,1} = B - C - m_{i,1,0}$ (9-19/V.34)
- If $B - C \geq M$, then $m_{i,1,1} = M - 1 - F$ and $m_{i,1,0} = B - C - m_{i,1,1}$ (9-20/V.34)

- If $D < M$, then $m_{i,2,0} = G$ and $m_{i,2,1} = D - m_{i,2,0}$ (9-21/V.34)
- If $D \geq M$, then $m_{i,2,1} = M - 1 - G$ and $m_{i,2,0} = D - m_{i,2,1}$ (9-22/V.34)

- If $A - B - D < M$, then $m_{i,3,0} = H$ and $m_{i,3,1} = A - B - D - m_{i,3,0}$ (9-23/V.34)
- If $A - B - D \geq M$, then $m_{i,3,1} = M - 1 - H$ and $m_{i,3,0} = A - B - D - m_{i,3,1}$ (9-24/V.34)

9.5 Differential Encoder

In each 4D symbol interval $m = 4i + j$, the two bits $(I2_{i,j}, I3_{i,j})$ shall be converted into an integer

$$I(m) = I2_{i,j} + 2 \cdot I3_{i,j} \qquad (9\text{-}25/V.34)$$

A differential encoder shall generate an integer $Z(m)$ as the modulo-4 sum of $I(m)$ and the previously generated integer $Z(m - 1)$ as shown in Figure 6.

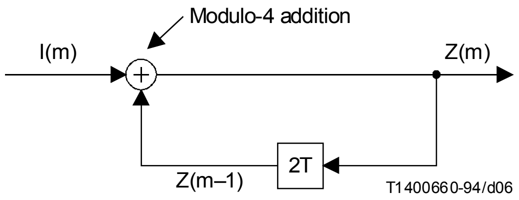


FIGURE 6/V.34

Differential Encoder

9.6 Mapper, Precoder and Trellis Encoder

The operations to implement the mapper, precoder and the trellis encoder are interdependent. Table 11 gives a sequence of steps for implementing the operations.

TABLE 11/V.34

Sequence of Operations for Mapper, Precoder and Trellis Encoder

Step	Inputs	Operation	Outputs
1	$Z(m)$, $v(2m)$	9.6.1	$u(2m)$
2	$u(2m)$, $c(2m)$, $p(2m)$	9.6.2, item 4	$y(2m)$, $x(2m)$
3	$x(2m)$	9.6.2, items 1-3	$c(2m + 1)$, $p(2m + 1)$
4	$c(2m)$, $c(2m + 1)$	9.6.3.3	$C_0(m)$
5	$C_0(m)$, $Y_0(m)$, $V_0(m)$	9.6.3	$U_0(m)$
6	$Z(m)$, $U_0(m)$, $v(2m + 1)$	9.6.1	$u(2m + 1)$
7	$u(2m + 1)$, $c(2m + 1)$, $p(2m + 1)$	9.6.2, item 4	$y(2m + 1)$, $x(2m + 1)$
8	$x(2m + 1)$	9.6.2, items 1-3	$c(2m + 2)$, $p(2m + 2)$
9	$y(2m)$, $y(2m + 1)$	9.6.3.1, 9.6.3.2	$Y_0(m + 1)$

9.6.1 Mapper

For each 2D symbol interval n = 8i + 2j + k, from the q-bit subgroup ($Q_{i,j,k,1}$, $Q_{i,j,k,2}$, ..., $Q_{i,j,k,q}$) and the ring index $m_{i,j,k}$, the mapper shall compute a mapping index Q(n):

$$Q(n) = Q_{i,j,k,1} + 2^1 \cdot Q_{i,j,k,2} + 2^2 \cdot Q_{i,j,k,3} + \ldots + 2^{q-1} \cdot Q_{i,j,k,q} + 2^q \cdot m_{i,j,k} \quad (9\text{-}26/V.34)$$

For each 4D symbol interval m = 4i + j, the mapping indices Q(2m) and Q(2m + 1) label two signal points v(2m) and v(2m + 1), respectively, from the quarter superconstellation of Figure 5. The output 2D signal points u(2m) and u(2m + 1) are obtained by rotating v(2m) by Z(m) · 90 degrees clockwise and v(2m + 1) by [Z(m) + 2 · $I1_{i,j}$ + U_0(m)] · 90 degrees clockwise, respectively. The bit U_0(m) is the output of the trellis encoder, and is obtained according to the method described in 9.6.3.

NOTE – For precoding interoperability, it is important that u(2m) and u(2m + 1) are generated exactly.

9.6.2 Precoder

The precoder shown in Figure 7 receives the complex-valued signal points u(n) from the mapper and generates the complex-valued signal x(n) according to:

$$x(n) = u(n) + c(n) - p(n) \quad (9\text{-}27/V.34)$$

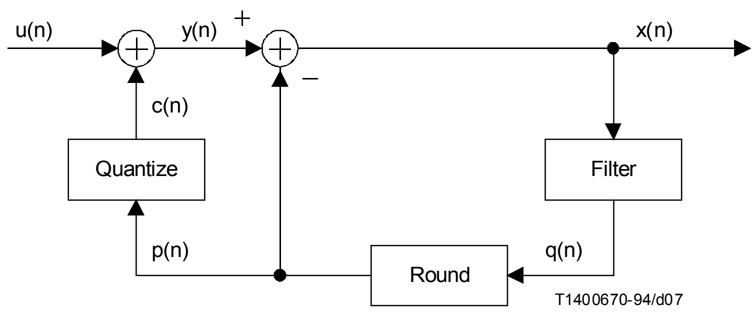


FIGURE 7/V.34

Block Diagram of Precoder

The complex-valued signals c(n) and p(n) are determined according to the algorithm specified below. The precoded signal x(n) is provided to the non-linear encoder and the signals c(n) and y(n) = u(n) + c(n), indicated in Figure 7, are provided to the trellis encoder.

NOTE – To ensure interoperability, the signals x(n), c(n) and y(n) must be *precisely* the same as in the algorithm specified below.

The complex-valued precoding coefficients {h(p), p = 1, 2, 3} are provided by the receiving modem during Phase 4 of the modem start-up procedures described in 11.4. or 12.4. Their real and imaginary components are represented in the 16-bit two's-complement format with 14 bits after the binary point, and assume values in the half-open interval (–2, 2). The coefficients shall be constrained such that the absolute value of the real and imaginary components of y(n) always satisfy abs[$y_{r,i}$(n)] ≤ 255.

The precoder shall determine the signals x(n), c(n) and y(n) based on the input u(n), the precoding coefficients {h(p), p = 1, 2, 3} and the three most recent precoded symbols {x(n – p), p = 1, 2, 3}, as follows:

1) Compute the filter output using complex arithmetic according to:

$$q(n) = \sum_{p=1}^{3} x(n - p)h(p) \quad (9\text{-}28/V.34)$$

2) Round the real and imaginary components of q(n) to the respective nearest integer multiples of 2^{-7} to obtain p(n). When a component falls exactly half-way between two integer multiples of 2^{-7}, round it to the one with the smaller magnitude.

3) Quantize the real and imaginary components of p(n) to the respective nearest integer multiple of 2w to obtain c(n). When a component falls exactly half-way between two integer multiples of 2w, quantize it to the one with the smaller magnitude.

Here the scale factor w is:

$$w = 1, \text{ when } b < 56$$
$$= 2, \text{ when } b \geq 56 \qquad (9\text{-}29/V.34)$$

where b is the number of bits in a high mapping frame as defined in Table 7.

4) Compute the channel output signal y(n) and the precoded signal x(n) according to:

$$y(n) = u(n) + c(n) \qquad (9\text{-}30/V.34)$$
$$x(n) = y(n) - p(n) \qquad (9\text{-}31/V.34)$$

9.6.3 Trellis Encoder

The trellis encoder shown in Figure 8 generates the bit $U_0(m)$ for the mapper once every 4D interval m.

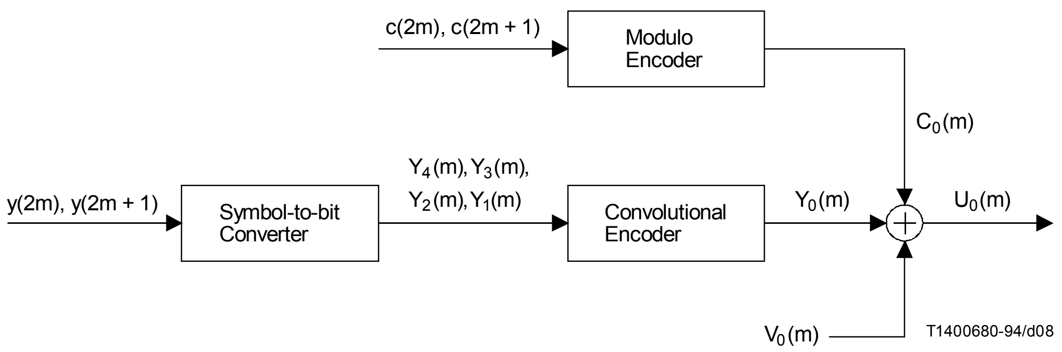


FIGURE 8/V.34

Block Diagram of Trellis Encoder

The trellis encoder consists of a convolutional encoder which generates an output bit $Y_0(m)$ and a modulo encoder which generates an output bit $C_0(m)$. $U_0(m)$ is then determined as the modulo 2 sum

$$U_0(m) = Y_0(m) \oplus C_0(m) \oplus V_0(m) \qquad (9\text{-}32/V.34)$$

where the bit $V_0(m)$ represents bit inversions for purposes of superframe synchronization. Bit inversions are introduced in the 4D symbol interval in the beginning of each half data frame (i.e. when m is an integer multiple of 2P), according to the periodic bit inversion pattern specified in Table 12. The left-most bit corresponds to the first half data frame of a superframe. The period of the bit inversion pattern is 16 when J = 8, and 14 when J = 7.

TABLE 12/V.34

Bit inversion patterns

J	Pattern
8	01 11 01 11 11 11 10 10
7	01 11 01 11 11 11 10

9.6.3.1 Symbol-to-Bit Converter

The symbol-to-bit converter generates four bits $[Y_4(m), Y_3(m), Y_2(m), Y_1(m)]$ as follows:

The complex 2D channel output symbols y(2m) and y(2m + 1) lie on a 2D rectangular grid with odd-integer coordinates. The signal points on the grid are represented by a 3-bit subset label in an 8-way set partition. This labelling of points is shown in Figure 9 for a small subset of the points near the origin.

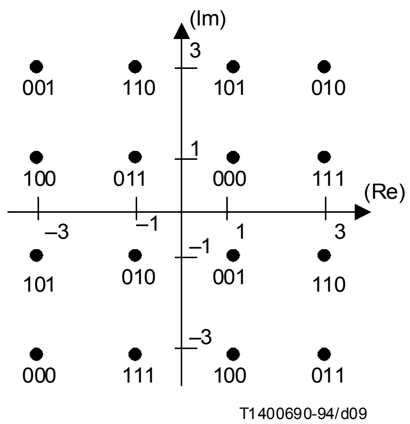


FIGURE 9/V.34

Labelling of channel output points y(2m) or y(2m + 1)

Two channel output symbols y(2m) and y(2m + 1) are used to generate two subset labels s(2m) and s(2m + 1), respectively, which are converted into four input bits $[Y_4(m), Y_3(m), Y_2(m), Y_1(m)]$ for the convolutional encoder according to Table 13.

TABLE 13/V.34

Table for $[Y_4(m), Y_3(m), Y_2(m), Y_1(m)]$

	s(2m + 1)							
s(2m)	000	001	010	011	100	101	110	111
000	0000	0000	0001	0001	1000	1000	1001	1001
001	0011	0010	0010	0011	1011	1010	1010	1011
010	0101	0101	0100	0100	1101	1101	1100	1100
011	0110	0111	0111	0110	1110	1111	1111	1110
100	1000	1000	1001	1001	0000	0000	0001	0001
101	1011	1010	1010	1011	0011	0010	0010	0011
110	1101	1101	1100	1100	0101	0101	0100	0100
111	1110	1111	1111	1110	0110	0111	0111	0110

9.6.3.2 Convolutional Encoder

The bits [Y_4(m), Y_3(m), Y_2(m), Y_1(m)] are put into one of the systematic convolutional encoders shown in Figures 10, 11 and 12. The convolutional encoder generates an output bit Y_0(m). There is an inherent delay of one 4D symbol interval in the convolutional encoder. Therefore, the output Y_0(m) does not depend on the current input [Y_4(m), Y_3(m), Y_2(m), Y_1(m)].

The encoder shall be selected by the receiving modem during Phase 4 of the start-up procedures specified in 11.4 or 12.4. The following encoders are available:

– 16-state rate-2/3 (Figure 10);

– 32-state rate-3/4 (Figure 11);

– 64-state rate-4/5 (Figure 12).

For the 32-state encoder, the input bit Y_3(m) is not used. For the 16-state encoder, the input bits Y_4(m) and Y_3(m) are not used.

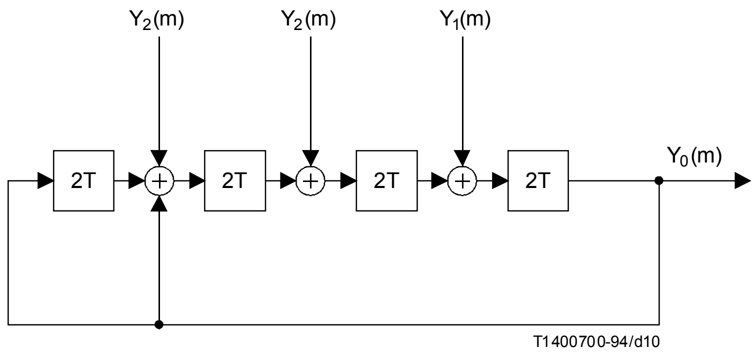


FIGURE 10/V.34

16-state convolutional encoder

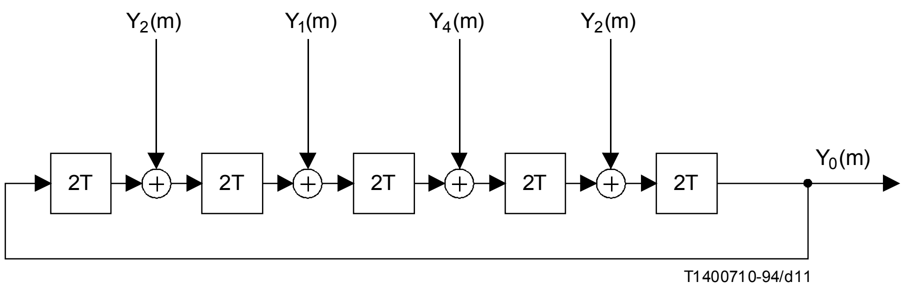


FIGURE 11/V.34

32-state convolutional encoder

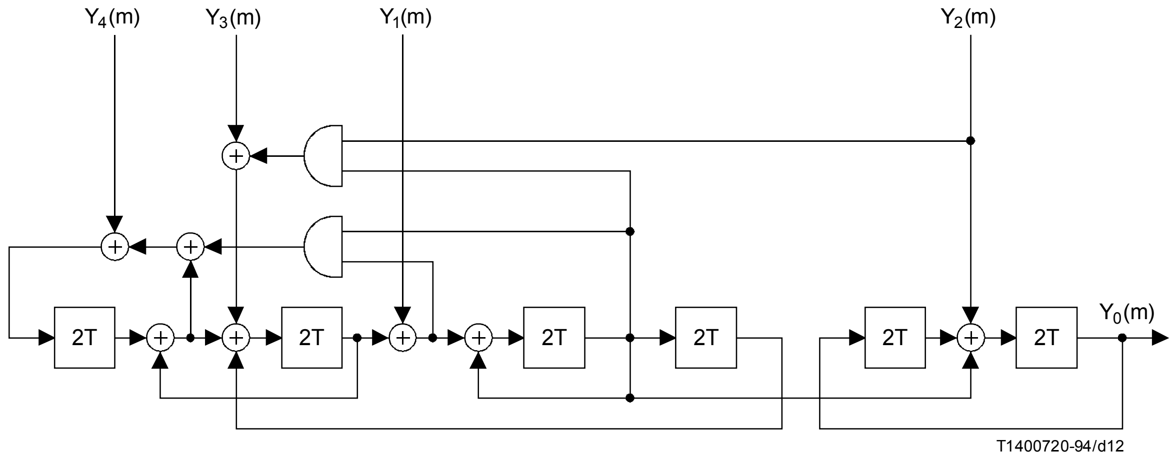


FIGURE 12/V.34

64-state convolutional encoder

9.6.3.3 Modulo Encoder

The modulo encoder uses the 2D integer signals c(2m) and c(2m + 1) to generate the bit $C_0(m)$ as follows: If the sum of the real and imaginary components of c(2m)/2 and the sum of the real and imaginary components of c(2m + 1)/2 are both even or both odd, then $C_0(m) = 0$; otherwise $C_0(m) = 1$.

9.7 Non-linear Encoder

The signal x(n) is non-linear encoded according to:

$$x'(n) = \Phi(n) \times (n) \qquad (9\text{-}33/V.34)$$

where the non-linear projection function is:

$$\Phi(n) = 1 + \zeta(n)/6 + \zeta^2(n)/120 \qquad (9\text{-}34/V.34)$$

and

$$\zeta(n) = \frac{\Theta[x_r^2(n) + x_i^2(n)]}{\overline{[x_r^2(n) + x_i^2(n)]}} \qquad (9\text{-}35/V.34)$$

where $\overline{[x_r^2(n) + x_i^2(n)]}$ represents the average energy of the signal x(n). The constant Θ has two possible values, 0 or 0.3125, and is selected during Phase 4 of start-up.

10 Start-up Signals and Sequences

This clause details the various signals and bit sequences used during modem start-up for both duplex and half-duplex operation.

NOTE – Although some of the signals used during start-up have the same nomenclature as variables defined in clauses 5 to 9, they are not related.

10.1 Signals and Sequences Used in Duplex Operation

10.1.1 Phase 1

All signals in Phase 1 shall be transmitted at the nominal transmit power level.

10.1.1.1 ANS

Answer tone as defined in Recommendation V.25.

10.1.1.2 ANSam

As defined in Recommendation V.8.

10.1.1.3 CI

As defined in Recommendation V.8.

10.1.1.4 CJ

As defined in Recommendation V.8.

10.1.1.5 CM

As defined in Recommendation V.8.

10.1.1.6 JM

As defined in Recommendation V.8.

10.1.2 Phase 2

During Phase 2, all signals except L1 shall be transmitted at the nominal transmit power level. If a recovery mechanism returns the modem to Phase 2 from a later phase, the transmit level shall revert to the nominal transmit power if the return point is before the L1, L2 probing segments. Otherwise, the previously negotiated transmit power level shall be maintained.

10.1.2.1 A

Tone A is a 2400 Hz tone transmitted by the answer modem. Transitions between A and $\overline{A}$, and similarly between $\overline{A}$ and A, are 180 degree phase reversals in the 2400 Hz tone. During the transmission of A and $\overline{A}$, the answer modem sends an 1800 Hz guard tone without any phase reversals. Tone A is transmitted at 1 dB below the nominal transmit power while the guard tone is transmitted at 7 dB below the nominal transmit power.

NOTE – The bandwidth of a tone with phase reversals should not be constrained in a way that appreciably affects the accuracy of round-trip delay measurements.

10.1.2.2 B

Tone B is a 1200 Hz tone transmitted by the call modem. Transitions between B and $\overline{B}$, and similarly between $\overline{B}$ and B, are 180 degree phase reversals in the 1200 Hz tone.

NOTE – The bandwidth of a tone with phase reversals should not be constrained in a way that appreciably affects the accuracy of round-trip delay measurements.

10.1.2.3 INFO Sequences

INFO sequences are used to exchange modem capabilities, results of line probing, and data mode modulation parameters. Two sets of INFO sequences are used: (INFO0a, INFO0c) and (INFO1a, INFO1c), where “a” identifies INFO sequences sent by the answer modem, and “c” identifies INFO sequences sent by the call modem. During start-up error recovery, two additional sequences are used to indicate an error condition: INFOMARKSa and INFOMARKSc.

10.1.2.3.1 Modulation

All INFO sequences are transmitted using binary DPSK modulation at 600 bit/s ± 0.01%. The transmit point is rotated 180 degrees from the previous point if the transmit bit is a 1, and the transmit point is rotated 0 degrees from the previous point if the transmit bit is a 0. Each INFO sequence is preceded by a point at an arbitrary carrier phase. When multiple INFO sequences are transmitted as a group, only the first sequence is preceded by a point at an arbitrary carrier phase.

INFO sequences are transmitted by the answer modem with a carrier frequency of 2400 Hz ± 0.01%, at 1 dB below the nominal transmit power, plus an 1800 Hz ± 0.01% guard tone 7 dB below the nominal transmit power. INFO sequences are transmitted by the call modem with a carrier frequency of 1200 Hz ± 0.01% at the nominal transmit power.

The transmitted line signal shall have a magnitude spectrum within the limits shown in Figure 13.

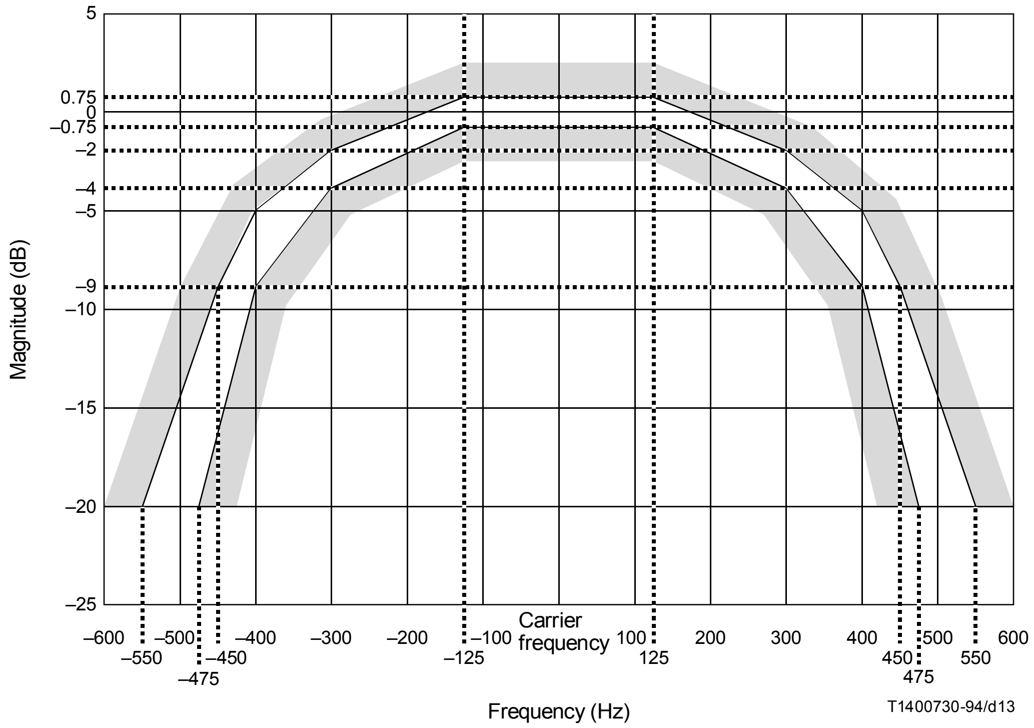


FIGURE 13/V.34

Transmit spectrum template for INFO modulation

NOTE – It is highly desirable to design linear phase transmitter channel separation and shaping filters since there are no provisions for adaptive equalizer training.

10.1.2.3.2 CRC Generator

The CRC is formed by passing all of the information bits in a sequence, except the frame sync bits, the start bits, and the fill bits, through the CRC generator described in Figure 14.

The CRC is calculated by dividing a binary sequence by the specified polynomial. The polynomial used to compute the CRC is: $x^{16} + x^{12} + x^5 + 1$. The CRC is calculated as follows:

1) load the shift register in the CRC generator with all ones;

2) shift in the binary sequence;

3) output the contents of the shift register, starting with bit 0 in Figure 14. Bit 0 of the CRC is the LSB.

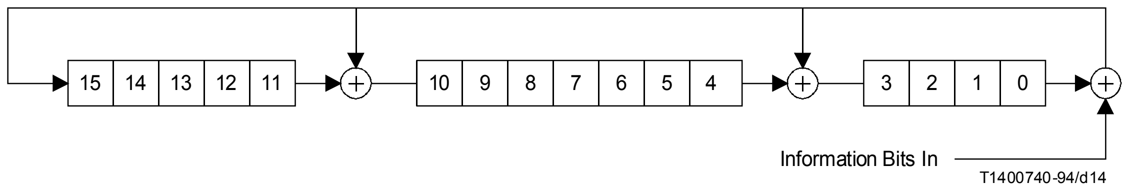


FIGURE 14/V.34

CRC Generator

10.1.2.3.3 INFO0 Information Bits

Table 14 defines the bits in the INFO0 sequences. Bit 0 is transmitted first.

TABLE 14/V.34

Definition of bits in INFO0 sequences

INFO0 Bit(s) LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame Sync: 01110010, where the left-most bit is first in time.
12	Set to 1 indicates symbol rate 2743 is supported.
13	Set to 1 indicates symbol rate 2800 is supported.
14	Set to 1 indicates symbol rate 3429 is supported.
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000.
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000.
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200.
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200.
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed.
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting.
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps.
24	Set to 1 in an INFO0 sequence transmitted from a CME modem.
25	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
26:27	Transmit clock source: 0 = internal, 1 = synchronized to receive timing, 2 = external, 3 = reserved for ITU.
28	Set to 1 to acknowledge correct reception of an INFO0 frame during error recovery.
29:44	CRC
45:48	Fill bits: 1111

NOTES

1 Bits 12 through 14 are used to indicate the modem's capabilities and/or configuration. The values of bits 15 through 20 depend upon regulatory requirements and apply only to the modem's transmitter.

2 Bit 24 may be used in conjunction with the GSTN Access Category octet defined in Recommendation V.8 to determine the optimum parameters for the signal convertors and error-control functions in the call and answer modem and any intervening CME.

10.1.2.3.4 INFO1c Information Bits

Table 15 defines the bits in the INFO1c sequence. Bit 0 is transmitted first.

TABLE 15/V.34

Definition of bits in the INFO1c sequence

INFO1c Bit(s) LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame Sync: 01110010, where the left-most bit is first in time.
12:14	Minimum power reduction to be implemented by the answer modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if INFO0a indicated that the answer modem transmitter cannot reduce its power.
15:17	Additional power reduction, below that indicated by bits 12-14, which can be tolerated by the call modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if INFO0a indicated that the answer modem transmitter cannot reduce its power.
18:24	Length of MD to be transmitted by the call modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments.
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the answer modem to the call modem for a symbol rate of 2400.
26:29	Pre-emphasis filter to be used in transmitting from the answer modem to the call modem for a symbol rate of 2400. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3 and 4).
30:33	Projected maximum data rate for a symbol rate of 2400. These bits form an integer between 0 and 12 which gives the projected data rate as a multiple of 2400 bits/s. A 0 indicates the symbol rate can not be used.
34:42	Probing results pertaining to a final symbol rate selection of 2743 symbols per second. The coding of these 9 bits is identical to that for bits 25-33.
43:51	Probing results pertaining to a final symbol rate selection of 2800 symbols per second. The coding of these 9 bits is identical to that for bits 25-33.
52:60	Probing results pertaining to a final symbol rate selection of 3000 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the answer modem capabilities indicated in INFO0a.
61:69	Probing results pertaining to a final symbol rate selection of 3200 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the answer modem capabilities indicated in INFO0a.
70:78	Probing results pertaining to a final symbol rate selection of 3429 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the answer modem capabilities indicated in INFO0a.
79:88	Frequency offset of the probing tones as measured by the call modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 88 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy can not be achieved, the integer shall be set to –512 indicating that this field is to be ignored.
89:104	CRC
105:108	Fill bits: 1111

10.1.2.3.5 INFO1a Information Bits

Table 16 defines the bits in the INFO1a sequence. Bit 0 is transmitted first.

TABLE 16/V.34

Definition of bits in the INFO1a sequence

INFO1a Bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame Sync: 01110010, where the left-most bit is first in time.
12:14	Minimum power reduction to be implemented by the call modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if INFO0c indicated that the call modem transmitter cannot reduce its power.
15:17	Additional power reduction, below that indicated by bits 12:14, which can be tolerated by the answer modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if INFO0c indicated that the call modem transmitter cannot reduce its power.
18:24	Length of MD to be transmitted by the answer modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments.
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the call modem to the answer modem. This shall be consistent with the capabilities of the call modem indicated in INFO0c.
26:29	Pre-emphasis filter to be used in transmitting from the call modem to the answer modem. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3 and 4).
30:33	Projected maximum data rate for the selected symbol rate from the call modem to the answer modem. These bits form an integer between 0 and 12 which gives the projected data rate as a multiple of 2400 bits/s.
34:36	Symbol rate to be used in transmitting from the answer modem to the call modem. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429. The symbol rate selected shall be consistent with information in INFO1c and consistent with the symbol rate asymmetry allowed as indicated in INFO0a and INFO0c. The carrier frequency and pre-emphasis filter to be used are those already indicated for this symbol rate in INFO1c.
37:39	Symbol rate to be used in transmitting from the call modem to the answer modem. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429. The symbol rate selected shall be consistent with the capabilities indicated in INFO0a and consistent with the symbol rate asymmetry allowed as indicated in INFO0a and INFO0c.
40:49	Frequency offset of the probing tones as measured by the answer modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 49 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy can not be achieved, the integer shall be set to –512 indicating that this field is to be ignored.
50:65	CRC
66:69	Fill bits: 1111

10.1.2.3.6 INFOMARKS

INFOMARKSc is transmitted by the call modem by applying binary ones to the DPSK modulator described in 10.1.2.3.1.

INFOMARKSa is transmitted by the answer modem by applying binary ones to the DPSK modulator described in 10.1.2.3.1.

10.1.2.4 Line Probing Signals

Two line probing signals, L1 and L2, are used to analyse channel characteristics. L1 is a periodic signal with a repetition rate of 150 ± 0.01% Hz which consists of a set of tones (cosines) spaced 150 Hz apart at frequencies from 150 Hz to 3750 Hz. Tones at 900 Hz, 1200 Hz, 1800 Hz, and 2400 Hz are omitted. The initial phase of each cosine is given in Table 17. L1 is transmitted for 160 ms (24 repetitions) at 6 dB above the nominal power level. L2 is the same as L1 but is transmitted for no longer than 550 ms plus a round-trip delay at the nominal power level.

NOTE – The probing tones should be generated with enough accuracy so as not to appreciably affect the channel distortion and noise measurements in the remote receiver.

TABLE 17/V.34

Probing tones

cos (2πft + φ)	
f (Hz)	φ (degrees)
150	0
300	180
450	0
600	0
750	0
1050	0
1350	0
1500	0
1650	180
1950	0
2100	0
2250	180
2550	0
2700	180
2850	0
3000	180
3150	180
3300	180
3450	180
3600	0
3750	0

10.1.3 Phases 3 and 4

All signals in Phases 3 and 4 are transmitted using the selected symbol rate, carrier frequency, pre-emphasis filter and power level.

NOTE – The transmitter should compensate for modulation factors including the effects of non-linear encoding and precoding so that the average signal power transmitted in Phases 3 and 4 is maintained in segment B1 and the subsequent data mode.

10.1.3.1 B1

Sequence B1 consists of one data frame of scrambled ones transmitted at the end of start-up using the selected data mode modulation parameters. Bit inversions for superframe synchronization are inserted as if the data frame were the last data frame in a superframe. Prior to transmission of B1, the scrambler, trellis encoder, differential encoder, and the precoding filter tap delay line are initialized to zeroes.

10.1.3.2 E

E is a 20-bit sequence of binary ones used to signal the end of MP. It is mapped into a sequence of symbols chosen from the 4 or 16-point 2D constellation depending on the signal J. The 4-point E sequence is generated as described in 10.1.3.3. The 16-point E sequence is generated as described in 10.1.3.9.

10.1.3.3 J

Sequence J consists of a whole number of repetitions of one of the two 16-bit patterns shown in Table 18. J indicates constellation size used by the remote modem for transmitting sequences TRN, MP, MP′, and E during Phase 4 training. J is a sequence of symbols generated by applying input bits to the scrambler defined in clause 7. Two scrambled bits, $I1_n$ and $I2_n$, are transmitted every 2D symbol interval, where $I1_n$ is the first bit in time. Integers $I_n = 2 \cdot I2_n + I1_n$ are differentially encoded to generate the integer Z_n as the modulo 4 sum of I_n and Z_{n-1}. The transmitted points are obtained by rotating point 0 from the quarter-superconstellation of Figure 5 clockwise by $Z_n \cdot 90$ degrees. The differential encoder shall be initialized using the final symbol of the transmitted TRN sequence.

TABLE 18/V.34

Definition of bits in J sequence

Constellation Size	Bits 0-15
4-point	0000100110010001, where the left-most bit is first in time
16-point	0000110110010001, where the left-most bit is first in time

10.1.3.4 J′

Sequence J′ is used to terminate J and is transmitted only once. J′ is generated as described in 10.1.3.3 except that the 16-bit pattern shown in Table 19 is used.

TABLE 19/V.34

Definition of bits in J′ sequence

Bits J′	Definition
0-15	1111100110010001, where the left-most bit is first in time

10.1.3.5 MD

MD is an optional Manufacturer-Defined signal used by a transmitting modem to train its echo canceller if this can not be accommodated by the TRN signal in Phase 3. The length of the MD signal is indicated in the transmitting modem's INFO1 sequence. If the signal is not present, the MD length indication will be 0.

10.1.3.6 PP

Signal PP consists of six periods of a 48-symbol sequence and is used by the remote modem for training its equalizer. PP(i), i = 0, 1, ..., 287, is defined as follows:

Set $i = 4k + I$

where

$k = 0, 1, 2, ..., 71$ and

$I = 0, 1, 2, 3$ for each k

then:

$$PP(i) = e^{j\pi(kI+4)/6} \quad \text{if k modulo 3 = 1}$$
$$= e^{j\pi kI/6} \quad \text{otherwise} \qquad (10\text{-}1/V.34)$$

PP(0) is transmitted first.

10.1.3.7 S

Signal S is transmitted by alternating between point 0 of the quarter-superconstellation of Figure 5 and the same point rotated counterclockwise by 90 degrees. Signal $\overline{S}$ is transmitted by alternating between point 0 rotated by 180 degrees and point 0 rotated counterclockwise by 270 degrees. The signal S shall end with the transmission of point 0 rotated counterclockwise by 90 degrees. Signal $\overline{S}$ shall begin with the transmission of point 0 rotated by 180 degrees.

10.1.3.8 TRN

Signal TRN is a sequence of symbols generated by applying binary ones to the input of the scrambler described in clause 7. The scrambled bits are mapped to a 4 or 16-point 2D constellation depending on the signal J.

The 4-point TRN signal is generated by using two scrambled bits, $I1_n$ and $I2_n$, which are transmitted every 2D symbol interval, where I1n is the first bit in time. The transmitted points are obtained by rotating point 0 from the quarter-superconstellation of Figure 5 clockwise by $I_n \cdot 90$ degrees, where $I_n = 2 \cdot I2_n + I1_n$.

The 16-point TRN signal is generated by using four scrambled bits, $I1_n$, $I2_n$, $Q1_n$, and $Q2_n$, which are transmitted every 2D symbol interval and $I1_n$ is the first bit in time. The transmitted points are obtained by using integer $2 \cdot Q2_n + Q1_n$ to select a point from the quarter-superconstellation of Figure 5 and then rotating that point clockwise by $I_n \cdot 90$ degrees, where $I_n = 2 \cdot I2_n + I1_n$.

The scrambler is initialized to zero prior to transmission of the TRN signal.

10.1.3.9 Modulation Parameter (MP) Sequences

Modulation Parameter (MP) Sequences are exchanged between modems during start-up and rate renegotiations and contain modulation parameters to be used for data mode transmission.

Two types of MP sequences are used in duplex mode. Type 0 contains maximum call-to-answer-modem data signalling rate, maximum answer-to-call modem data signalling rate, amount of constellation shaping, trellis encoder choice, non-linear encoding parameter, auxiliary channel enable, data signalling rate capability mask, and 16 bits reserved for future use. Type 1 is the same as Type 0 with the addition of fields for precoding coefficients. The bit fields for the two types of MP sequences used in duplex mode are defined in Tables 20 and 21. The CRC generator used is described in 10.1.2.3.2.

An MP sequence with the acknowledge bit set to 1 is denoted by MP′.

MP sequences consist of symbols chosen from a 4 or 16-point constellation depending upon the signal J. The 4-point MP sequence is generated as described in 10.1.3.3.

The 16-point MP sequence is generated by using four scrambled bits, $I1_n$, $I2_n$, $Q1_n$, and $Q2_n$, which are transmitted every 2D symbol interval where $I1_n$ is the first bit in time. Integer $2 \cdot Q2_n + Q1_n$ selects the point from the quarter-superconstellation of Figure 5. Integers $I_n = 2 \cdot I2_n + I1_n$ are differentially encoded to generate integer Z_n as the modulo 4 sum of I_n and Z_{n-1}. Finally, the transmitted point is obtained by clockwise rotation of the selected point by $Z_n \cdot 90$ degrees. The differential encoder shall be initialized using the final symbol of the transmitted TRN sequence.

Either type (Type 0 or Type 1) of MP sequence may be sent during start-up, retrain, or rate renegotiation. Prior to receiving the first MP sequence in Phase 4, the precoding coefficients are initialized to 0. If a Type 0 sequence is received, the precoding coefficients are unaffected.

TABLE 20/V.34

Definition of bits in MP sequence Type 0

MP Bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	Type: 0
19	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
20:23	Maximum call modem to answer modem data signalling rate. Data rate = N · 2400 where N is a four-bit integer between 1 and 12.
24:27	Maximum answer modem to call modem data signalling rate. Data rate = N · 2400 where N is a four-bit integer between 1 and 12.
28	Auxiliary channel select bit. Set to 1 if modem is capable of supporting and enables auxiliary channel. Auxiliary channel is used only if both modems set this bit to 1.
29:30	Trellis encoder select bits: 0 = 16 state, 1 = 32 state, 2 = 64 state, 3 = reserved for ITU. Receiver requires remote-end transmitter to use selected trellis encoder.
31	Non-linear encoder parameter select bit for the remote-end transmitter. 0: $\Theta = 0$, 1: $\Theta = 0.3125$
32	Constellation shaping select bit for the remote-end transmitter. 0: minimum, 1: expanded (see Table 10).
33	Acknowledge bit. 0 = modem has not received MP from far end. 1 = received MP from far end.
34	Start bit: 0
35:49	Data signalling rate capability mask. Bit 35:2400; bit 36:4800; bit 37:7200; ...; bit 46:28 800; bits 47, 48, 49: reserved for ITU. (These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.) Bits set to 1 indicate data signalling rates supported and enabled in both transmitter and receiver of modem.
50	Asymmetric data signalling rate enable. Set to 1 indicates modem capable of asymmetric data signalling rates.
51	Start bit: 0
52:67	Reserved for ITU: These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.
68	Start bit: 0
69:84	CRC
85:87	Fill bits: 000

TABLE 21/V.34

Definition of bits in MP sequence Type 1

MP Bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	Type: 1
19	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
20:23	Maximum call modem to answer modem data signalling rate. Data rate = N · 2400 where N is a four-bit integer between 1 and 12.
24:27	Maximum answer modem to call modem data signalling rate. Data rate = N · 2400 where N is a four-bit integer between 1 and 12.
28	Auxiliary channel select bit. Set to 1 if modem is capable of supporting and enables auxiliary channel. Auxiliary channel is used only if both modems set this bit to 1.
29:30	Trellis encoder select bits: 0 = 16 state, 1 = 32 state, 2 = 64 state, 3 = reserved for ITU. Receiver requires remote-end transmitter to use selected trellis encoder.
31	Non-linear encoder parameter select bit for the remote-end transmitter. 0: $\Theta = 0$, 1: $\Theta = 0.3125$
32	Constellation shaping select bit for the remote-end transmitter. 0: minimum, 1: expanded (see Table 10).
33	Acknowledge bit. 0 = modem has not received MP from far end. 1 = received MP from far end.
34	Start bit: 0
35:49	Data signalling rate capability mask. Bit 35:2400; bit 36:4800; bit 37:7200; ...; bit 46:28 800; bits 47, 48, 49: reserved for ITU. (These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.) Bits set to 1 indicate data signalling rates supported and enabled in both transmitter and receiver of modem.
50	Asymmetric data signalling rate enable. Set to 1 indicates modem capable of asymmetric data signalling rates.
51	Start bit: 0
52:67	Precoding coefficient h(1) real.
68	Start bit: 0
69:84	Precoding coefficient h(1) imaginary.
85	Start bit: 0
86:101	Precoding coefficient h(2) real.
102	Start bit: 0
103:118	Precoding coefficient h(2) imaginary.
119	Start bit: 0
120:135	Precoding coefficient h(3) real.
136	Start bit: 0
137:152	Precoding coefficient h(3) imaginary.
153	Start bit: 0
154:169	Reserved for ITU: These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.
170	Start bit: 0
171:186	CRC
187	Fill bit: 0

10.2 Signals and Sequences Used in Half-duplex Operation

10.2.1 Phase 1

All signals in Phase 1 shall be transmitted at the nominal transmit power level. Signals used in Phase 1 of start-up for half-duplex operation are identical to those specified in 10.1.1.

10.2.2 Phase 2

During Phase 2, all signals except L1 shall be transmitted at the nominal transmit power level. Signals used in Phase 2 of start-up for half-duplex operation are identical to those specified in 10.1.2, except that INFO1a and INFO1c are replaced by INFOh.

10.2.2.1 INFOh Bits

Table 22 defines the bits in the INFOh sequence.

TABLE 22/V.34

Definition of bits in INFOh sequence

INFOh Bit(s) LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame Sync: 01110010, where the left-most bit is first in time.
12:14	Power reduction requested by the recipient modem receiver. An integer between 0 and 7 gives the requested power reduction in dB. These bits shall indicate 0 if the source modem's INFO0 indicated that the source modem transmitter cannot reduce its power.
15:21	Length of TRN to be transmitted by the source modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments.
22	Set to 1 indicates the high carrier frequency is to be used in data mode transmission. This must be consistent with the capabilities indicated in the source modem's INFO0.
23:26	Pre-emphasis filter to be used in transmitting from the source modem to the recipient modem. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3 and 4).
27:29	Symbol rate to be used for data transmission. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429.
30	Set to 1 indicates TRN uses a 16-point constellation, 0 indicates TRN uses a 4-point constellation.
31:46	Code CRC
47:50	Fill bits: 1111

10.2.3 Phase 3

All signals in Phase 3 are transmitted using the selected symbol rate, carrier frequency, preemphasis filter, and power level.

NOTE – The transmitter should compensate for modulation factors including the effects of non-linear encoding and precoding so that the average signal power transmitted in Phase 3 is maintained in segment B1 and the subsequent data mode.

10.2.3.1 PP

As defined in 10.1.3.6.

10.2.3.2 S

As defined in 10.1.3.7.

10.2.3.3 Sh

Signal Sh is transmitted by alternating between point 0 of the quarter-superconstellation of Figure 5 and the same point rotated counterclockwise by 90 degrees. Signal $\overline{\text{Sh}}$ is transmitted by alternating between point 0 rotated by 180 degrees and point 0 rotated counterclockwise by 270 degrees. Signal Sh shall end with the transmission of point 0 rotated counterclockwise by 90 degrees. Signal $\overline{\text{Sh}}$ shall begin with the transmission of point 0 rotated by 180 degrees. Signals Sh and $\overline{\text{Sh}}$ are transmitted using the control channel modulation described in 10.2.4.

10.2.3.4 TRN

TRN is a sequence of symbols chosen from the 4 or 16-point 2D constellation depending on bit 30 of INFOh.

The 4-point TRN sequence and the 16-point TRN sequence are generated as defined in 10.1.3.8.

10.2.4 Control channel modulation

The control channel is transmitted using 1200 bit/s or 2400 bit/s QAM modulation using a symbol rate of 600 ± 0.01% symbol/s. Training and synchronization signals for the control channel are transmitted at 1200 bit/s. The control channel data is scrambled using the scrambler defined in clause 7.

The answer modem shall transmit with a carrier frequency of 2400 ± 0.01% Hz, at 1 dB below the nominal transmit power level, plus an 1800 ± 0.01% Hz guard tone at a level 7 dB below the nominal transmit power level. The call modem shall transmit with a 1200 ± 0.01% Hz carrier at the nominal transmit power level. The transmitted line signal shall have a magnitude spectrum within the limits shown in Figure 13.

For a data rate of 1200 bit/s, 2 bits are transmitted every symbol interval. For a data rate of 2400 bit/s, 4 bits are transmitted every symbol interval. These bits are labelled I1, I2, Q1, Q2, where I1 is the first bit in time and Q2 is the last bit in time. If only 2 bits are transmitted, the Q1 and Q2 bits are set to 0. Uncoded transmission is used.

The transmitted point is obtained by using $2 \cdot Q2 + Q1$ to select a point from the quarter superconstellation of Figure 5. Then the point is rotated clockwise by $Z_n \cdot 90$ degrees, where the two-bit integer Z_n is formed from the modulo 4 sum of $2 \cdot I2_n + I1_n$ and Z_{n-1}. If differential encoding is not enabled, $Z_n = 2 \cdot I2_n + I1_n$.

10.2.4.1 AC

Signal AC is the alternating transmission of point 0 of the quarter-superconstellation of Figure 5 and point 0 rotated by 180 degrees.

10.2.4.2 ALT

Signal ALT is transmitted using the control channel modulation with the differential encoder enabled and consists of scrambled alternations of binary 0 and 1 at 1200 bit/s. The initial state of the scrambler shall be all zeroes.

10.2.4.3 E

E is a 20-bit sequence of scrambled binary ones used to signal the beginning of control channel user data. It uses the control channel modulation at 1200 bit/s with the differential encoder enabled.

10.2.4.4 Modulation Parameter (MPh) Sequences

Modulation Parameter (MPh) Sequences are exchanged between modems during start-up and control channel resynchronization. They contain modulation parameters to be used for data mode transmission.

MPh sequences are transmitted using the control channel modulation at 1200 bit/s with the differential encoder and scrambler enabled as described in 10.2.4.

There are two types of MP sequences used in half-duplex mode (MPh). Type 0 contains maximum source modem data signalling rate, control channel data signalling rate, trellis encoder choice, non-linear encoding parameter, amount of shaping, data signalling rate capability mask, and bits reserved for future use. Type 1 is the same as Type 0 with the addition of fields for precoding coefficients. The bit fields for the two types of MPh sequences used in half-duplex mode are defined in Tables 23 and 24.

Either type (Type 0 or Type 1) of MPh sequence may be sent. Prior to receiving the first MPh sequence during control channel start-up, the precoding coefficients are initialized to 0. If a Type 0 sequence is received, the precoding coefficients are unaffected.

TABLE 23/V.34

Definition of bits in MPh sequence Type 0

MPh Bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	Type: 0
19	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
20:23	Maximum data signalling rate. Data rate = N · 2400 where N is a four-bit integer between 1 and 12.
24:26	Reserved for ITU: These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.
27	Control channel data signalling rate selected for remote transmitter. 0 = 1200 bit/s, 1 = 2400 bit/s.
28	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
29:30	Trellis encoder select bits: 0 = 16 state, 1 = 32 state, 2 = 64 state, 3 = reserved for ITU. Receiver requires remote-end transmitter to use selected trellis encoder.
31	Non-linear encoder parameter select bit for the remote-end transmitter. 0: $\Theta = 0$, 1: $\Theta = 0.3125$
32	Constellation shaping select bit for the remote-end transmitter. 0: minimum, 1: expanded (see Table 10).
33	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
34	Start bit: 0
35:49	Data signalling rate capability mask. Bit 35:2400; bit 36:4800; bit 37:7200; ...; bit 46:28 800; bits 47, 48, 49: reserved for ITU. (These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.) Bits set to 1 indicate data signalling rates supported and enabled in both transmitter and receiver of modem.
50	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
51	Start bit: 0
52:67	Reserved for ITU: These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.
68	Start bit: 0
69:84	CRC
85:87	Fill bits: 000
NOTE – Source modem does not use bits 29-32, and should set these bits to 0.	

TABLE 24/V.34

Definition of bits in MPh sequence Type 1

MPh Bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	Type: 1
19	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
20:23	Maximum data signalling rate. Data rate = N · 2400 where N is a four bit integer between 1 and 12.
24:26	Reserved for ITU: These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.
27	Control channel data signalling rate selected for remote transmitter. 0 = 1200 bit/s, 1 = 2400 bit/s.
28	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
29:30	Trellis encoder select bits: 0 = 16 state, 1 = 32 state, 2 = 64 state, 3 = reserved for ITU. Receiver requires remote-end transmitter to use selected trellis encoder.
31	Non-linear encoder parameter select bit for the remote-end transmitter. 0: $\Theta = 0$, 1: $\Theta = 0.3125$
32	Constellation shaping select bit for the remote-end transmitter. 0: minimum, 1: expanded (see Table 10).
33	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
34	Start bit: 0
35:49	Data signalling rate capability mask. Bit 35:2400; bit 36:4800; bit 37:7200; ...; bit 46:28 800; bits 47, 48, 49: reserved for ITU. (These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.) Bits set to 1 indicate data signalling rates supported and enabled in both transmitter and receiver of modem.
50	Reserved for ITU: This bit is set to 0 by the transmitting modem and is not interpreted by the receiving modem.
51	Start bit: 0
52:67	Precoding coefficient h(1) real.
68	Start bit: 0
69:84	Precoding coefficient h(1) imaginary.
85	Start bit: 0
86:101	Precoding coefficient h(2) real.
102	Start bit: 0
103:118	Precoding coefficient h(2) imaginary.
119	Start bit: 0
120:135	Precoding coefficient h(3) real.
136	Start bit: 0
137:152	Precoding coefficient h(3) imaginary.
153	Start bit: 0
154:169	Reserved for ITU: These bits are set to 0 by the transmitting modem and are not interpreted by the receiving modem.
170	Start bit: 0
171:186	CRC
187	Fill bit: 0
NOTE – Source modem does not use bits 29-32, and should set these bits to 0.	

10.2.4.5 PPh

PPh consists of four periods of an 8-symbol sequence and is used in half-duplex mode for control channel receiver initialization and resynchronization. The sequence PPh(i), i = 0, 1, ..., 31, is defined as follows:

Set i = 2k + I,

where

k = 0, 1, 2, ..., 15 and

I = 0, 1 for each k

then:

$$PPh(i) = e^{j\pi\left[\frac{2k(k-l)+1}{4}\right]} \qquad (10\text{-}2/V.34)$$

PPh(0) is transmitted first.

11 Duplex Operating Procedures

There are two duplex modes of operation defined, GSTN and two-wire leased line. For GSTN operation, the modem shall proceed according to 11.1. For two-wire leased line operation, the modem shall proceed according to 11.8.

11.1 Phase 1 – Network Interaction

11.1.1 Call Modem

11.1.1.1 Initially, the call modem shall condition its receiver to detect either signal ANS or ANSam as defined in Recommendation V.8, and the modem shall transmit CI, CT or CNG as defined in Recommendation V.8.

If signal ANSam is detected, the modem shall transmit silence for the period T_e as specified in Recommendation V.8. The modem shall then condition its receiver to detect JM and sends CM with the appropriate bits set in the modulation modes category to indicate that V.34 operation is desired. When a minimum of two identical JM sequences have been received, the modem shall complete the current CM octet and send CJ. After sending CJ, the modem shall transmit silence for 75 ± 5 ms and proceed with Phase 2. This procedure is shown in Figure 15.

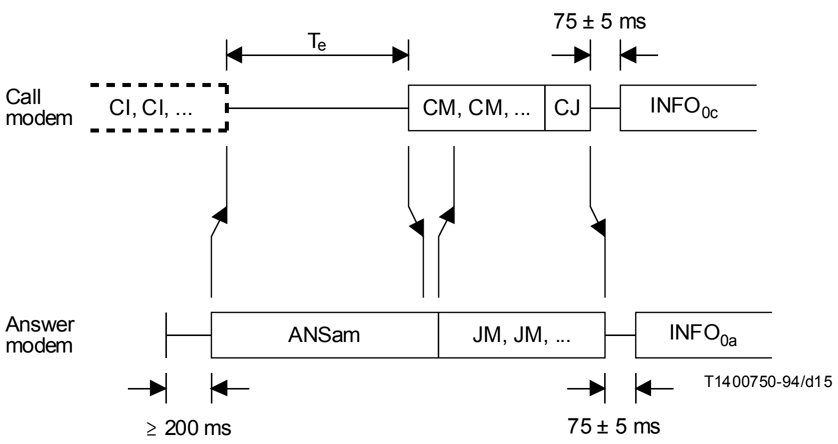


FIGURE 15/V.34

Phase 1 – Network interaction with a CM/JM exchange

11.1.1.2 If the JM modulation mode bits indicate V.34 duplex operation, the modem shall proceed in accordance with 11.2. If half-duplex V.34 operation is indicated, the modem shall proceed in accordance with 12.2. If V.34 operation is not indicated, the modem shall proceed in accordance with Recommendation V.8.

11.1.1.3 If signal ANS (rather than ANSam) is detected, the modem shall proceed in accordance with Annex A/V.32 *bis*, Recommendation T.30, or other appropriate Recommendation.

11.1.2 Answer Modem

11.1.2.1 Upon connection to line, the modem shall initially remain silent for a minimum of 200 ms and then transmit signal ANSam according to the procedure in Recommendation V.8. If duplex operation is intended, this signal shall include phase reversals as specified in Recommendation V.8. If half-duplex operation is intended, phase reversals are optional. The modem shall condition its receiver to detect CM and, possibly, calling modem responses from other appropriate Recommendations.

11.1.2.2 If a minimum of 2 identical CM sequences are received and the modulation mode bits indicate V.34 operation, the modem shall send JM and condition its receiver to detect CJ. After receiving all 3 octets of CJ, the modem shall transmit silence for 75 ± 5 ms, and proceed with Phase 2 of start-up. This procedure is shown in Figure 15.

11.1.2.3 If the JM modulation mode bits indicate V.34 duplex operation, the modem shall proceed in accordance with 11.2. If half-duplex V.34 operation is indicated, the modem shall proceed in accordance with 12.2. If V.34 operation is not indicated, the modem shall proceed in accordance with Recommendation V.8.

11.1.2.4 If a call modem response from some other appropriate Recommendation is detected, the modem shall proceed in accordance with the appropriate Recommendation.

11.1.2.5 If neither CM nor a suitable call modem response is detected for the allowed ANSam transmission period as specified in Recommendation V.8, the modem shall transmit silence for 75 ± 5 ms, and then proceed in accordance with Annex A/V.32 *bis*, Recommendation T.30, or other appropriate Recommendation.

11.2 Phase 2 – Probing/Ranging

Channel probing and ranging are performed in Phase 2 of the start-up procedure. The description below details both error-free and recovery procedures in the call and answer modems (see Figures 16, 17 and 18). Capabilities information and modulation parameters are sent in the INFO sequences detailed in 10.1.2.3.

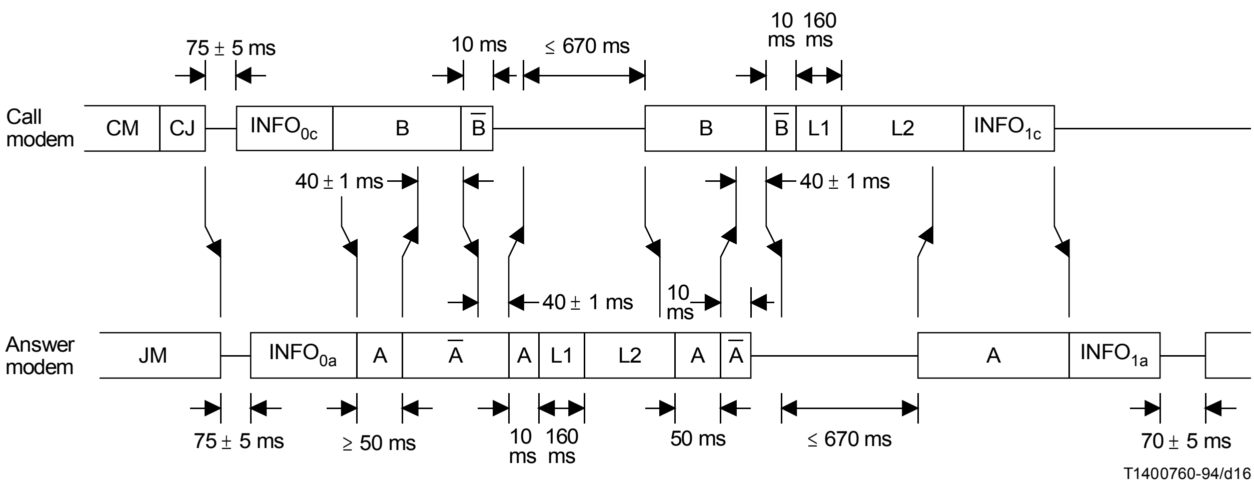


FIGURE 16/V.34

Phase 2 – Probing/Ranging

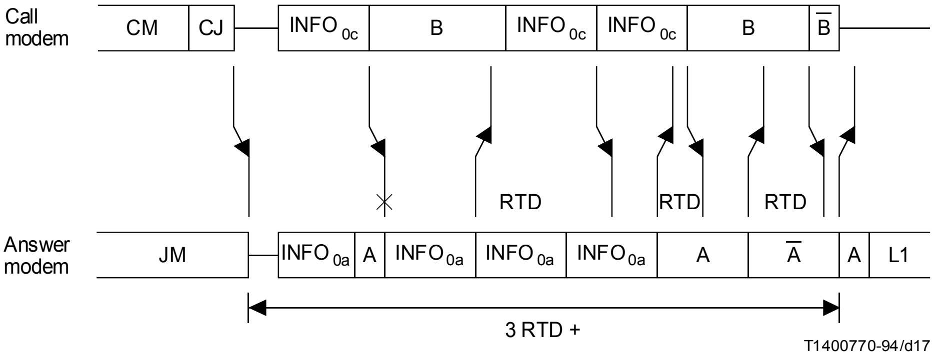


FIGURE 17/V.34

Answer modem does not correctly receive INFO0c

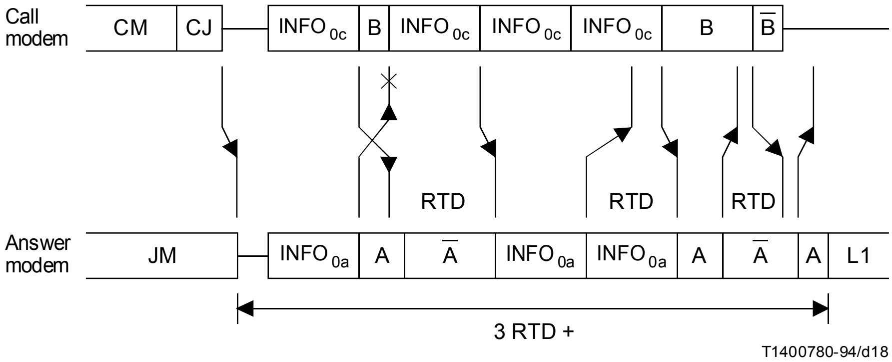


FIGURE 18/V.34

Call modem does not correctly receive INFO0a

11.2.1 Error Free Procedures

11.2.1.1 Call Modem

11.2.1.1.1 During the 75 ± 5 ms silent period ending Phase 1, the call modem shall condition its receiver to receive INFO0a and detect Tone A. After the 75 ± 5 ms silent period, the call modem shall send INFO0c with bit 28 set to 0, followed by Tone B.

11.2.1.1.2 After receiving INFO0a, the call modem shall condition its receiver to detect Tone A and the subsequent Tone A phase reversal.

11.2.1.1.3 After detecting the Tone A phase reversal, the call modem shall transmit a Tone B phase reversal. The Tone B phase reversal shall be delayed so that the time duration between receiving the Tone A phase reversal at the line terminals and the appearance of the Tone B phase reversal at the line terminals is 40 ± 1 ms. Tone B shall be transmitted for another 10 ms after the phase reversal. The modem shall then transmit silence and condition its receiver to detect a second Tone A phase reversal.

11.2.1.1.4 After detecting the second Tone A phase reversal, the call modem can calculate the round-trip delay. The round-trip delay estimate, RTDEc, is the time interval between the appearance of the Tone B phase reversal at the modem line terminals and receiving the second Tone A phase reversal at the line terminals minus 40 ms. The modem shall then condition its receiver to receive the probing signals L1 and L2.

11.2.1.1.5 The call modem shall receive signal L1 for its 160 ms duration. The call modem may then receive signal L2 for a period of time not to exceed 500 ms. The call modem shall then transmit Tone B and condition its receiver to detect Tone A and the subsequent Tone A phase reversal.

11.2.1.1.6 After detecting Tone A and the subsequent Tone A phase reversal, the call modem shall transmit a Tone B phase reversal. The Tone B phase reversal shall be delayed so that the time duration between receiving the Tone A phase reversal at the line terminals and the appearance of the Tone B phase reversal at the line terminals is 40 ± 1 ms. Tone B shall be transmitted for an additional 10 ms after the phase reversal. The modem shall then transmit signal L1 followed by signal L2 and condition its receiver to detect Tone A.

11.2.1.1.7 After the call modem detects Tone A and has received the local echo of L2 for a period of time not to exceed 550 ms plus a round-trip delay, the modem shall send INFO1c.

11.2.1.1.8 After sending INFO1c, the call modem shall transmit silence and condition its receiver to receive INFO1a. After receiving INFO1a, the modem shall proceed to Phase 3 of the start-up procedure.

11.2.1.2 Answer Modem

11.2.1.2.1 During the 75 ± 5 ms silent period ending Phase 1, the answer modem shall condition its receiver to receive INFO0c and detect Tone B. After the 75 ± 5 ms silent period the answer modem shall send INFO0a with bit 28 set to 0, followed by Tone A.

11.2.1.2.2 After receiving INFO0c, the modem shall condition its receiver to detect Tone B and receive INFO0c.

11.2.1.2.3 After Tone B is detected and Tone A has been transmitted for at least 50 ms, the answer modem shall transmit a Tone A phase reversal, and condition its receiver to detect a Tone B phase reversal.

11.2.1.2.4 After detecting the Tone B phase reversal, the answer modem can calculate the round-trip delay. The round-trip delay estimate, RTDEa, is the time interval between sending the Tone A phase reversal at the line terminals and receiving the Tone B phase reversal at the line terminals minus 40 ms.

11.2.1.2.5 The answer modem shall then transmit a Tone A phase reversal. The Tone A phase reversal shall be delayed so that the time duration between receiving the Tone B phase reversal (as in 11.2.1.2.4) at the line terminals and the appearance of the Tone A phase reversal at the line terminals is 40 ± 1 ms. Tone A shall be transmitted for 10 ms after the phase reversal. Then the modem shall transmit signal L1 followed by signal L2 and condition its receiver to detect Tone B.

11.2.1.2.6 When Tone B is detected and the answer modem has received the local echo of L2 for a period of time not to exceed 550 ms plus a round-trip delay, the answer modem shall transmit Tone A for 50 ms followed by a Tone A phase reversal. Tone A shall be transmitted for an additional 10 ms after the phase reversal. Then the modem shall transmit silence and condition its receiver to detect a Tone B phase reversal.

11.2.1.2.7 After detecting the Tone B phase reversal, the modem shall condition its receiver to receive the probing signals L1 and L2.

11.2.1.2.8 The answer modem shall receive signal L1 for its 160 ms duration. The answer modem may then receive signal L2 for a period of time not to exceed 500 ms. The answer modem shall then transmit Tone A and condition its receiver to receive INFO1c.

11.2.1.2.9 After receiving INFO1c, the modem shall send INFO1a. After sending INFO1a, the modem shall proceed to Phase 3 of the start-up procedure.

11.2.2 Recovery Mechanisms

11.2.2.1 Call Modem

11.2.2.1.1 If, in 11.2.1.1.2 or 11.2.1.1.3, the call modem detects Tone A before receiving INFO0a, or if it receives repeated INFO0a sequences, the call modem shall repeatedly send INFO0c sequences.

If the call modem receives INFO0a with bit 28 set to 1, it shall condition its receiver to detect Tone A and the subsequent Tone A phase reversal, complete sending the current INFO0c sequence, and then transmit Tone B. Alternatively, if the call modem detects Tone A and has received INFO0a, it shall condition its receiver to detect a Tone A phase reversal, complete sending the current INFO0c sequence, and transmit Tone B. In both cases, the call modem shall then proceed according to 11.2.1.1.3.

11.2.2.1.2 If, in 11.2.1.1.3, the call modem does not detect the Tone A phase reversal, the call modem shall continue transmitting Tone B until it does detect a Tone A phase reversal.

11.2.2.1.3 If, in 11.2.1.1.4, the call modem does not detect a Tone A phase reversal within 2000 ms from the phase reversal detected in 11.2.1.1.3, the call modem shall transmit silence and condition its receiver to detect Tone A. After detecting Tone A, the call modem shall transmit Tone B and condition its receiver to detect a Tone A phase reversal and proceed in accordance with 11.2.1.1.3.

11.2.2.1.4 If, in 11.2.1.1.6, the call modem does not detect the Tone A phase reversal within 900 ms plus a round-trip delay from the phase reversal detected in 11.2.1.1.4, the modem waits 40 ms, then transmits a Tone B phase reversal. Tone B shall be transmitted for an additional 10 ms after the phase reversal. The modem shall then transmit signal L1 followed by signal L2, condition its receiver to detect Tone A, and proceed in accordance with 11.2.1.1.7.

11.2.2.1.5 If, in 11.2.1.1.7, the call modem does not detect Tone A within 650 ms plus a round-trip delay from the beginning of L2, the call modem shall initiate a retrain according to 11.5.1.1.

11.2.2.1.6 If, in 11.2.1.1.8, the call modem does not receive INFO1a within 700 ms plus a round-trip delay from the end of INFO1c transmission, the call modem shall condition its receiver to detect either Tone A or INFOMARKSa. Upon detection of INFOMARKSa, the call modem shall either initiate a retrain according to 11.5.1.1 or send INFO1c and proceed in accordance with 11.2.1.1.8. Upon detection of Tone A, the call modem shall respond to a retrain and proceed according to 11.5.1.2.

NOTE – The call modem shall set bit 28 of sequence INFO0c to 1 after correctly receiving INFO0a.

11.2.2.2 Answer Modem

11.2.2.2.1 If, in 11.2.1.2.2, 11.2.1.2.3, or 11.2.1.2.4, the answer modem detects Tone B before correctly receiving INFO0c, or if it receives repeated INFO0c sequences, the modem shall repeatedly send INFO0a.

If the answer modem receives INFO0c with bit 28 set to 1, it shall condition its receiver to detect Tone B, complete the current INFO0a, and then transmit Tone A. Alternatively, if the answer modem detects Tone B and has received INFO0c, it shall complete the current INFO0a, and transmit Tone A. In both cases, the answer modem shall then proceed according to 11.2.1.2.3.

11.2.2.2.2 If, in 11.2.1.2.4, the answer modem does not detect the Tone B phase reversal within 2000 ms, the answer modem shall condition its receiver to detect Tone B and then proceed according to 11.2.1.2.3.

11.2.2.2.3 If, in 11.2.1.2.6, the answer modem does not detect Tone B within 600 ms plus a round-trip delay from the beginning of L2, the modem shall condition its receiver to detect Tone B and transmit Tone A. The answer modem shall then proceed according to 11.2.1.2.3.

11.2.2.2.4 If, in 11.2.1.2.9, the answer modem does not receive INFO1c within 2000 ms plus two round-trip delays from the detection of Tone B in 11.2.1.2.6, the modem shall either initiate a retrain according to 11.5.2.1 or send INFOMARKSa until it receives INFO1c or detects Tone B. If Tone B is detected, the answer modem shall proceed according to 11.5.2.2. If INFO1c is received, the answer modem shall then proceed according to 11.2.1.2.9.

NOTE – The answer modem shall set bit 28 of sequence INFO0a to 1 upon correctly receiving INFO0c.

11.3 Phase 3 – Equalizer and Echo Canceller Training

Equalizer and echo canceller training are performed in Phase 3 of the duplex start-up procedure. The description below details both the error-free and recovery procedures in the call and answer modems (see Figure 19).

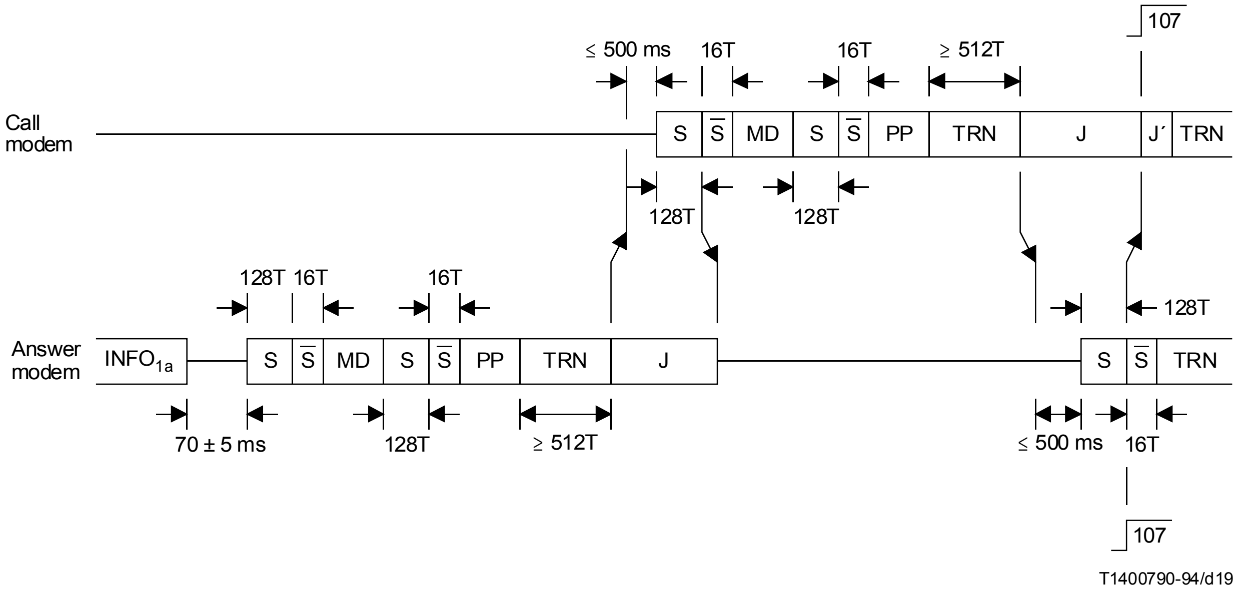


FIGURE 19/V.34

Phase 3 – Equalizer and Echo Canceller Training

11.3.1 Error Free Procedure

11.3.1.1 Call Modem

11.3.1.1.1 The call modem shall be initially silent and condition its receiver to detect S and the subsequent $\overline{S}$. If the duration of signal MD indicated by INFO1a is zero, the modem shall proceed according to 11.3.1.1.2. Otherwise, after detecting the S-to-$\overline{S}$ transition, the modem shall wait for the duration of signal MD as indicated by INFO1a and then shall condition its receiver to receive signal S and the S-to-$\overline{S}$ transition.

11.3.1.1.2 After detecting signal S and the S-to-$\overline{S}$ transition, the modem shall condition its receiver to begin training its equalizer using signal PP. After receiving signal PP, the modem may further refine its equalizer using the first 512T of signal TRN.

11.3.1.1.3 After receiving the first 512T of signal TRN, the modem shall condition its receiver to receive sequence J. After receiving J, the call modem may wait for up to 500 ms and then shall transmit signal S for 128T and signal $\overline{S}$ for 16T.

11.3.1.1.4 If the duration of the call modem's MD signal, as indicated in the previous INFO1c, is zero, the modem shall proceed according to 11.3.1.1.5. Otherwise, the modem shall transmit signal MD for the duration indicated in the previous INFO1c and then transmit S for 128T and signal $\overline{S}$ for 16T.

11.3.1.1.5 The call modem shall then transmit signal PP.

11.3.1.1.6 After transmitting signal PP, the modem shall transmit signal TRN. Signal TRN consists of four constellation points and shall be transmitted for at least 512T. The total time from the beginning of transmission of signal MD to the end of signal TRN shall not exceed two round-trip delays plus 2000 ms.

11.3.1.1.7 After transmitting signal TRN, the modem shall send sequence J and condition its receiver to detect signal S. After detecting signal S, the modem shall proceed to Phase 4 of the start-up.

11.3.1.2 Answer Modem

11.3.1.2.1 After sending sequence INFO1a, the modem shall transmit silence for 70 ±€5 ms, signal S for 128T and signal $\overline{S}$ for 16T. If the duration of the answer modem's MD signal, as indicated in the INFO1a, is zero, the modem shall proceed according to 11.3.1.2.2. Otherwise, the modem shall transmit signal MD for the duration indicated in INFO1a, signal S for 128T, and signal $\overline{S}$ for 16T.

11.3.1.2.2 The answer modem shall then transmit signal PP.

11.3.1.2.3 After transmitting signal PP, the modem shall transmit signal TRN. Signal TRN consists of four constellation points and shall be transmitted for at least 512T. The total time from the beginning of transmission of signal MD to the end of signal TRN shall not exceed one round-trip delay plus 2000 ms.

11.3.1.2.4 After transmitting signal TRN, the modem shall send sequence J and condition its receiver to detect signal S and the S-to-$\overline{S}$ transition. After detecting the S-to-$\overline{S}$ transition, the modem shall transmit silence. If the duration of signal MD indicated by INFO1c is zero, the modem shall proceed according to 11.3.1.2.5. Otherwise, it shall wait for the duration of signal MD as indicated by INFO1c and condition its receiver to detect signal S and the S-to-$\overline{S}$ transition. After detecting the S-to-$\overline{S}$ transition, the modem shall proceed according to 11.3.1.2.5.

11.3.1.2.5 The modem shall condition its receiver to begin its equalizer training using signal PP. The modem may further refine its equalizer using the first 512T of signal TRN.

11.3.1.2.6 After receiving the first 512T of signal TRN, the modem shall condition its receiver to receive sequence J. After receiving J, the answer modem may wait for up to 500 ms and shall then begin transmitting signal S. The modem shall then proceed to Phase 4 of the start-up.

11.3.2 Recovery Mechanisms

11.3.2.1 Call Modem

The call modem may initiate a retrain during Phase 3 according to 11.5.1.1.

11.3.2.1.1 If, in 11.3.1.1.3, sequence J is not received within 2800 ms plus two round-trip delays from the end of INFO1c transmission, the call modem shall condition its receiver to detect Tone A or receive INFOMARKSa. If Tone A is detected, the call modem shall respond to a retrain in accordance with 11.5.1.2. If INFOMARKSa is received, the call modem shall send INFO1c and proceed in accordance with 11.2.1.1.8.

11.3.2.2 Answer Modem

The answer modem may initiate a retrain during Phase 3 according to 11.5.2.1.

11.3.2.2.1 If, in 11.3.1.2.4, the S-to-$\overline{S}$ transition is not detected within 600 ms plus a round-trip delay from the start of sequence J, the answer modem shall transmit silence for 70 ± 5 ms, then send INFOMARKSa. The answer modem shall continue sending INFOMARKSa for the duration of the call modem's MD signal, then condition its receiver to detect Tone B or receive INFO1c. If Tone B is detected, the answer modem shall respond to a retrain according to 11.5.2.2. If INFO1c is received, the answer modem shall proceed in accordance with 11.2.1.2.9.

11.3.2.2.2 If, in 11.3.1.2.6, sequence J from the call modem is not received within 2600 ms plus two round-trip delays from the end of sequence J in 11.3.1.2.4, the modem shall send INFOMARKSa, and condition its receiver to detect Tone B or receive INFO1c. If Tone B is detected, the answer modem shall respond to a retrain according to 11.5.2.2. If INFO1c is received, the answer modem shall proceed in accordance with 11.2.1.2.9.

11.4 Phase 4 – Final Training

Final training of the modem in duplex mode and exchange of final data mode modulation parameters are performed in Phase 4 of the start-up procedure. The description below details both error-free and recovery procedures in the call and answer modems (see Figure 20). Data mode modulation parameters are passed in the MP sequences detailed in 10.1.3.9.

11.4.1 Error Free Procedure

11.4.1.1 Call Modem

11.4.1.1.1 After detecting S followed by $\overline{S}$, the call modem shall stop sending J sequences, condition its receiver to detect signal TRN, turn on circuit 107, transmit one J′ sequence, and then transmit signal TRN.

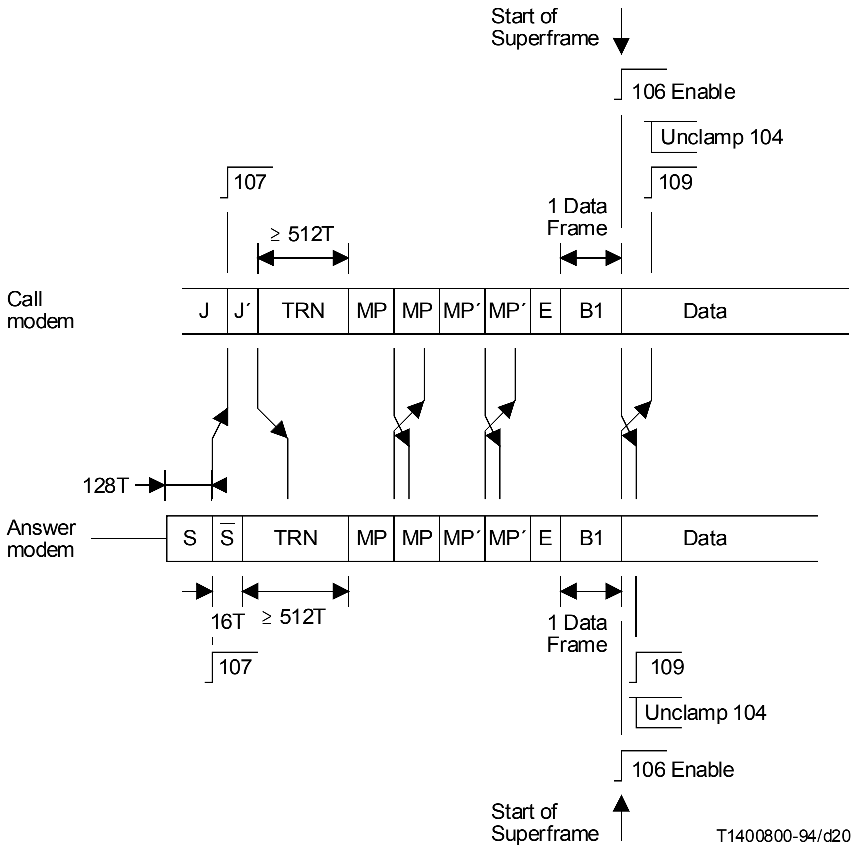


FIGURE 20/V.34

Phase 4 – Final Training

11.4.1.1.2 After transmitting signal TRN for a minimum of 512T, the modem shall condition its receiver to receive sequence MP and may continue sending TRN for up to 2000 ms. After training adequately, the call modem shall then cease transmitting TRN and send sequence MP. After receiving the answer modem's MP sequence, the call modem shall complete sending the current MP sequence and then send MP′ sequences (MP sequences with the acknowledge bit set).

11.4.1.1.3 The call modem shall continue sending MP′ sequences until it receives MP′ or E from the answer modem. The modem shall then complete the current MP′ sequence and then send a single 20-bit E sequence. The modem can then determine the data signalling rates in both directions as follows:

If bit 50 of MP is set to 0 (symmetric rates) by either the call or answer modems, the call modem's transmit and receive rate shall be the maximum rate enabled in both modems that is less than or equal to the call-to-answer and answer-to-call rates specified in both modems' MP sequences.

If both call and answer modems have bit 50 set to 1 (asymmetric rate) the call modem's transmit rate shall be the maximum rate enabled in both modems that is less than or equal to the call-to-answer rates specified in both modems' MP sequences. The call modem's receive rate shall be the maximum rate enabled in both modems that is less than or equal to the answer-to-call rates specified in both modems' MP sequences.

11.4.1.1.4 After sending an E sequence, the call modem shall send B1 at the negotiated data signalling rate using the data mode modulation parameters, enable circuit 106 to respond to the condition of circuit 105, start a new superframe, and begin data transmission using the modulation procedures of clauses 5 to 9.

11.4.1.1.5 After receiving a 20-bit E sequence, the modem shall condition its receiver to receive B1. After receiving B1, the modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

11.4.1.2 Answer Modem

11.4.1.2.1 The answer modem shall transmit signal S for 128T, condition its receiver to detect sequence J' followed by signal TRN, and turn on circuit 107. The modem shall then transmit signal $\overline{S}$ for 16T followed by signal TRN.

11.4.1.2.2 After receiving 512T of signal TRN, the answer modem shall condition its receiver to receive sequence MP and continue transmitting TRN until its receiver is trained adequately. The modem shall transmit TRN for at least 512T but no longer than 2000 ms plus a round-trip delay. It shall then send MP sequences. After receiving the call modem's MP sequence, the modem shall complete sending the current MP sequence, and then send MP′ sequences (MP sequences with the acknowledge bit set).

11.4.1.2.3 The answer modem shall continue sending MP sequences until it has sent an MP′ sequence and received P′ or E from the call modem. The modem shall then complete the current MP′ sequence and send a single 20-bit E sequence. The modem shall determine the data signalling rates as follows:

If bit 50 of MP is set to 0 (symmetric rates) by either the call or answer modem, the answer modem's transmit and receive rate shall be the maximum rate enabled in both modems that is less than or equal to the call-to-answer and answer-to-call rates specified in both modems' MP sequences.

If both call and answer modems have bit 50 set to 1 (asymmetric rate) the answer modem's transmit rate shall be the maximum rate enabled in both modems that is less than or equal to the answer-to-call rates specified in both modems' MP sequences. The answer modem's receive rate shall be the maximum rate enabled in both modems that is less than or equal to the call-to-answer rates specified in both modems' MP sequences.

11.4.1.2.4 After sending the E sequence, the answer modem shall send B1 at the negotiated data signalling rate using the data mode modulation parameters. The modem shall then enable circuit 106 to respond to the condition of circuit 105, start a new superframe, and begin data transmission using the modulation procedures of clauses 5 to 9.

11.4.1.2.5 After receiving a 20-bit E sequence, the answer modem conditions its receiver to receive B1. After receiving B1, the modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

Figure 20 shows the sequence of events during Phase 4.

11.4.2 Recovery Mechanism

11.4.2.1 Call Modem

If Tone A is detected during Phase 4, the call modem shall respond to a retrain according to 11.5.1.2. The call modem may initiate a retrain during Phase 4 according to 11.5.1.1.

11.4.2.1.1 If, in 11.4.1.1.1, the S-to-$\overline{S}$ transition is not detected within 600 ms plus a round-trip delay from the start of sequence J, the call modem shall transmit silence for 70 ± 5 ms, then send INFOMARKSc. The modem shall then condition its receiver to receive INFOMARKSa. After receiving INFOMARKSa, the call modem shall send INFO1c and proceed in accordance with 11.2.1.1.8.

11.4.2.1.2 If, after sending the J′ sequence, the modem has not received the E sequence for the following timeout period, it shall initiate the retrain procedure. If bit 24 in INFO0a is set to 1 (the CME bit in Table 14), the timeout period shall be 30 seconds. If bit 24 in INFO0a is set to 0, the timeout period shall be 2500 ms plus 2 round-trip delays.

11.4.2.2 Answer Modem

If Tone B is detected during Phase 4, the answer modem shall respond to a retrain according to 11.5.2.2. The answer modem may initiate a retrain during Phase 4 according to 11.5.2.1.

11.4.2.2.1 If, in 11.4.1.2.1, sequence J′ is not received within 100 ms plus a round-trip delay from the S-to-$\overline{S}$ transition, the answer modem shall condition its receiver to receive INFOMARKSc or Tone B. If INFORMARKSc is

received, the answer modem shall send INFOMARKSa, condition its receiver to receive INFO1c, and then proceed in accordance with 11.2.1.2.9. If Tone B is detected, the answer modem shall respond to a retrain according to 11.5.2.2.

11.4.2.2.2 If after transmitting signal $\overline{S}$, the modem has not received the E sequence for the following timeout period, it shall initiate the retrain procedure. If bit 24 in INFO0c is set to 1 (the CME bit in Table 14), the timeout period shall be 30 seconds. If bit 24 in INFO0c is set to 0, the timeout period shall be 2500 ms plus 3 round-trip delays.

11.5 Retrains

11.5.1 Call Modem

11.5.1.1 Initiating Retrain – To initiate a retrain, the call modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The call modem shall then transmit Tone B and condition its receiver to detect Tone A and receive INFO0a. If Tone A is detected, the call modem shall condition its receiver to detect a Tone A phase reversal and proceed in accordance with 11.2.1.1.3. If INFO0a is received, the modem shall proceed in accordance with 11.8.1.

11.5.1.2 Responding to Retrain – After detecting Tone A for more than 50 ms, the call modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The call modem shall then transmit Tone B, condition its receiver to detect a Tone A phase reversal, and proceed in accordance with 11.2.1.1.3.

11.5.2 Answer Modem

11.5.2.1 Initiating Retrain – To initiate a retrain, the answer modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The answer modem shall then transmit Tone A and condition its receiver to detect Tone B and receive INFO0c. If Tone B is detected and Tone A has been transmitted for at least 50 ms, the answer modem shall transmit a Tone A phase reversal and proceed according to 11.2.1.2.4. If INFO0c is received, the modem shall proceed according to 11.8.2.

11.5.2.2 Responding to Retrain – After detecting Tone B for more than 50 ms, the answer modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The answer modem shall then transmit Tone A and proceed in accordance with 11.2.1.2.3.

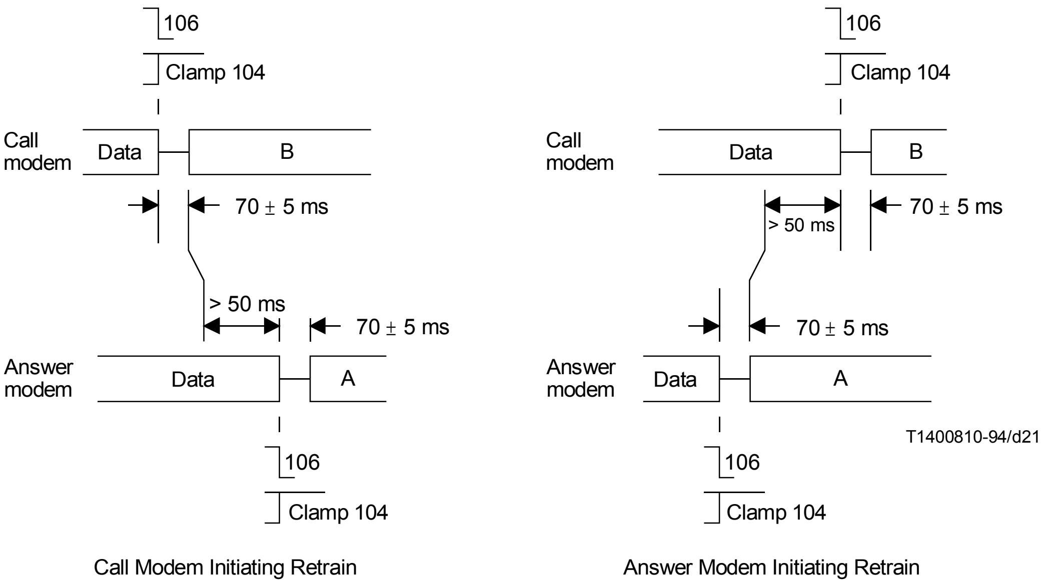


FIGURE 21/V.34

Retrain sequences in duplex mode

11.6 Rate Renegotiation

The rate renegotiation procedure can be initiated at any time during data mode to change to a new data signalling rate. This procedure can also be used to resynchronize the receiver without going through a complete retrain. In this case, signal TRN is transmitted until the receiver is prepared to enter data mode. Then the Modulation Parameters (MP) sequence is sent.

The TRN signal and the MP and E sequences are all sent using a 4-point constellation during rate renegotiation.

11.6.1 Error Free Procedure

11.6.1.1 Initiating Modem

11.6.1.1.1 To initiate a rate renegotiation, the modem shall turn OFF circuit 106, transmit signal S for 128T, followed by signal $\overline{S}$ for 16T. The modem may then transmit signal TRN for a maximum of 2000 ms plus a round-trip delay, followed by sequence MP.

11.6.1.1.2 After detecting signal S, the modem shall clamp circuit 104 to binary one and be conditioned to detect the S-to-$\overline{S}$ transition. After detecting the S-to-$\overline{S}$ transition, the modem shall condition its receiver to receive sequence MP. When the modem has received at least one MP sequence, and the modem is sending MP sequences, the modem shall complete sending the current MP sequence and then send MP′ sequences.

11.6.1.1.3 The initiating modem shall continue sending MP′ sequences until it has sent an MP′ sequence and received MP′ or E from the responding modem. The modem shall then complete the current MP′ sequence and send a single 20-bit E sequence. The initiating modem shall determine the data signalling rates as described in 11.4.1.1.3, if it is the call modem or in 11.4.1.2.3, if it is the answer modem.

11.6.1.1.4 After sending the E sequence, the initiating modem shall send B1 at the negotiated data signalling rate using the data mode modulation parameters. The modem shall then enable circuit 106 to respond to the condition of circuit 105, start a new superframe, and begin data transmission using the modulation procedures of clauses 5 to 9.

11.6.1.1.5 After receiving a 20-bit E sequence, the initiating modem shall condition its receiver to receive B1. After receiving B1, the modem shall unclamp circuit 104, and begin demodulating data.

11.6.1.2 Responding Modem

11.6.1.2.1 After detecting signal S, the responding modem shall clamp circuit 104 to binary one and be conditioned to detect the S-to-$\overline{S}$ transition. After detecting the S-to-$\overline{S}$ transition, the responding modem shall condition its receiver to detect sequence MP.

11.6.1.2.2 The responding modem shall then turn OFF circuit 106 and transmit signal S for 128T followed by signal $\overline{S}$ for 16T. The modem may then transmit signal TRN for a maximum of 2000 ms, followed by sequence MP. When the modem has received at least one MP sequence, and the modem is sending MP sequences, the modem shall complete sending the current MP sequence and then send MP′ sequences.

11.6.1.2.3 The responding modem shall continue transmitting MP′ sequences until it receives MP′ or E from the initiating modem. The modem shall then complete the current MP′ sequence and then send a single 20-bit E sequence. The responding modem shall determine the data signalling rates as described in 11.4.1.1.3, if it is the call modem or in 11.4.1.2.3, if it is the answer modem.

11.6.1.2.4 After sending an E sequence, the responding modem shall send B1 at the negotiated data signalling rate using the data mode modulation parameters, enable circuit 106 to respond to the condition of circuit 105, start a new superframe, and begin data transmission using the modulation procedures of clauses 5 to 9.

11.6.1.2.5 After receiving a 20-bit E sequence, the modem shall condition its receiver to receive B1. After receiving B1, the modem shall unclamp circuit 104, and begin demodulating data.

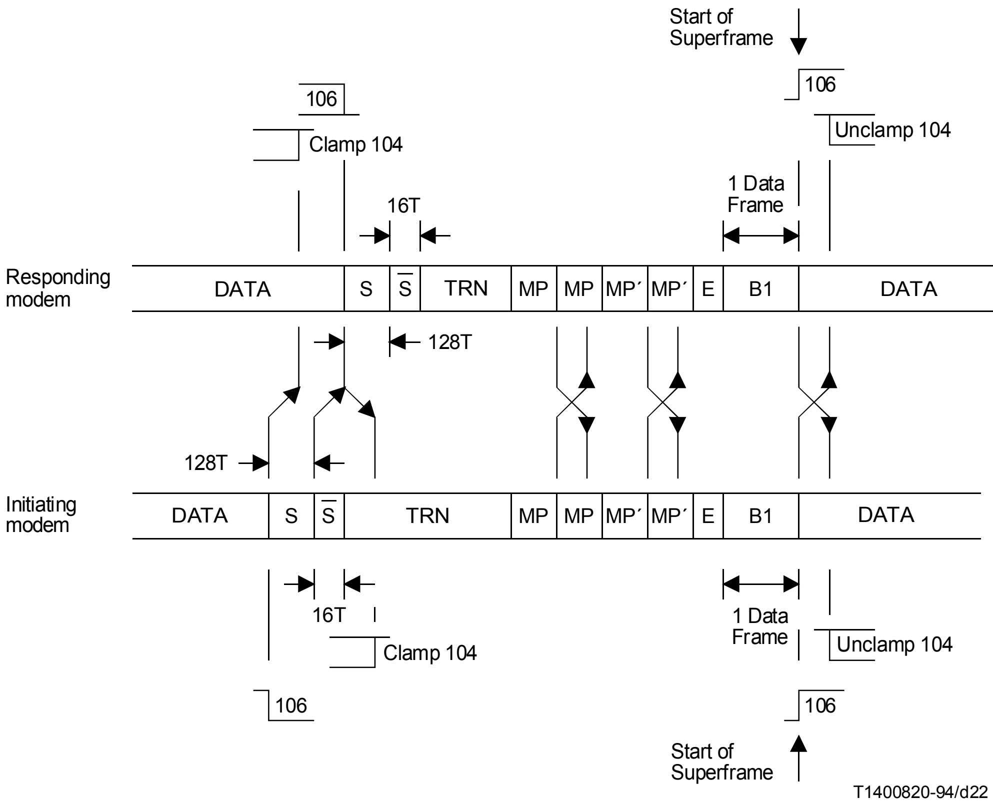


FIGURE 22/V.34

Rate Renegotiation – MP´ represents the MP signal with the acknowledge bit set

11.6.2 Recovery Mechanism

11.6.2.1 Initiating Modem

If the initiating modem is the call modem and Tone A is detected during rate renegotiation, the modem shall respond to a retrain according to 11.5.1.2, or it may initiate a retrain according to 11.5.1.1. If the initiating modem is the answer modem and Tone B is detected during rate renegotiation, the modem shall respond to a retrain according to 11.5.2.2, or it may initiate a retrain according to 11.5.2.1.

If after transmitting the S-to-$\overline{S}$ transition, the modem has not received sequence E for the following timeout period, it shall initiate the retrain procedure. If bit 24 in INFO0 is set to 1 (the CME bit in Table 14), the timeout period shall be 30 seconds. If bit 24 in INFO0 is set to 0, the timeout period shall be 2500 ms plus 2 round-trip delays.

11.6.2.2 Responding Modem

If the responding modem is the call modem and Tone A is detected during rate renegotiation, the modem shall respond to a retrain according to 11.5.1.2, or it may initiate a retrain according to 11.5.1.1. If the responding modem is the answer modem and Tone B is detected during rate renegotiation, the modem shall respond to a retrain according to 11.5.2.2, or it may initiate a retrain according to 11.5.2.1.

If after transmitting the S-to-$\overline{S}$ transition, the modem has not received sequence E for the following timeout period, it shall initiate the retrain procedure. If bit 24 in INFO0 is set to 1 (the CME bit in Table 14), the timeout period shall be 30 seconds. If bit 24 in INFO0 is set to 0, the timeout period shall be 2500 ms plus 3 round-trip delays.

11.7 Cleardown

The cleardown procedure can be initiated at any time during data mode to terminate a connection gracefully. This procedure is similar to the rate renegotiation procedure.

11.7.1 Initiating Modem

11.7.1.1 To initiate a cleardown, the initiating modem shall transmit signal S for 128T and condition its receiver to detect signal S. The modem shall then transmit signal $\overline{S}$ for 16T, and send MP sequences requesting zeros for the call-to-answer and answer-to-call data rates.

11.7.1.2 After detecting signal S from the responding modem, the initiating modem shall condition its receiver to detect $\overline{S}$ followed by MP sequences.

11.7.1.3 If the MP sequence from the responding modem has already been received, the modem shall send MP′ sequences rather than MP sequences. After receiving MP sequences, the initiating modem shall send MP′ sequences.

11.7.1.4 When the initiating modem is both receiving and sending MP′ sequences, it shall terminate the connection.

11.7.2 Responding Modem

11.7.2.1 If a modem in data mode receives signal S followed by $\overline{S}$, it becomes the responding modem. The responding modem shall stop transmitting data and transmit signal S for 128T followed by signal $\overline{S}$ for 16T.

11.7.2.2 The responding modem shall then send MP sequences and condition its receiver to receive the initiating modem's MP sequence as in a normal rate renegotiation. If the MP sequence from the initiating modem has already been detected, the modem shall send MP′ sequences rather than MP sequences. After detecting the MP sequence from the initiating modem, the responding modem shall send MP′ sequences.

11.7.2.3 After the responding modem has both received an MP′ sequence from the initiating modem requesting zeros for the call-to-answer and answer-to-call data signalling rates, and has sent an MP′ sequence, it shall then terminate the connection.

11.8 Two-wire Leased Line Operation

For two-wire leased line operation, one of the modems shall be configured as the call modem and the other shall be configured as the answer modem. The call modem shall operate according to 11.8.1 and the answer modem shall operate according to 11.8.2.

11.8.1 Call Modem

The call modem shall repeatedly send INFO0c sequences and condition its receiver to receive INFO0a. If the call modem receives INFO0a with bit 28 set to 1, it shall condition its receiver to detect Tone A and the subsequent Tone A phase reversal, complete sending the current INFO0c sequence, and then transmit Tone B. The modem shall then proceed according to 11.2.1.1.3.

NOTE – The call modem shall set bit 28 of the INFO0c sequence to 1 after correctly receiving the INFO0a sequence.

11.8.2 Answer Modem

The answer modem shall repeatedly send INFO0a sequences and condition its receiver to receive INFO0c. If the answer modem receives INFO0c with bit 28 set to 1, it shall condition its receiver to detect Tone B, complete sending the current INFO0a sequence, and then transmit Tone A. The modem shall then proceed according to 11.2.1.2.3.

NOTE – The answer modem shall set bit 28 of the INFO0a sequence to 1 after correctly receiving the INFO0c sequence.

12 Half-duplex Operating Procedures

Half-duplex operation in the context of this Recommendation describes a mode of operation where exchange of data alternates between unidirectional transmission of primary channel data from source to recipient modem and simultaneous bidirectional transmission of control channel data between the two modems.

12.1 Phase 1 – Network Interaction

Procedures for Phase 1 in half-duplex operation are identical to those specified in 11.1.

12.2 Phase 2 – Probing

Channel probing is performed in Phase 2 of the half-duplex start-up procedure. The description below details both error free and recovery procedures for the cases when the call modem is the source modem and the answer modem is the source modem. Capabilities information and modulation parameters are sent in the INFO sequences detailed in 10.1.2.3 and 10.2.2.1.

12.2.1 Call Modem as Source Modem

Figure 23 details Phase 2 procedures when the call modem is the source modem.

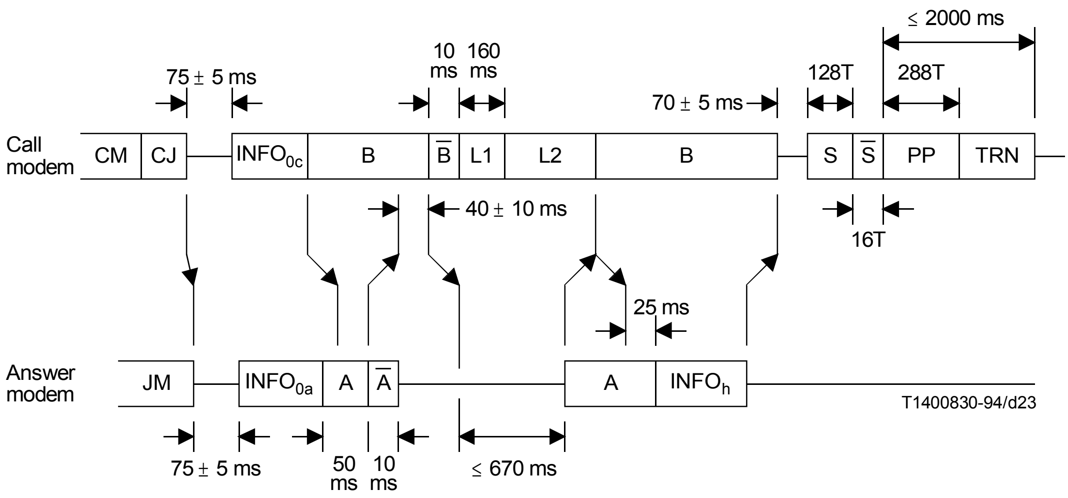


FIGURE 23/V.34

Phases 2 and 3 – Call modem is source modem

12.2.1.1 Call Modem Error Free Operation

12.2.1.1.1 During the 75 ± 5 ms silent period ending Phase 1, the call modem shall condition its receiver to receive INFO0a and detect Tone A. After the 75 ± 5 ms silent period, the call modem shall send INFO0c with bit 28 set to 0, followed by Tone B.

12.2.1.1.2 After receiving INFO0a, the modem shall condition its receiver to detect Tone A and the subsequent Tone A phase reversal.

12.2.1.1.3 After detecting the Tone A phase reversal, the call modem shall wait 40 ± 10 ms and transmit a Tone B phase reversal. Tone B shall be transmitted for another 10 ms after the phase reversal, and then the modem shall transmit signal L1 for 160 ms. The modem shall then transmit signal L2 and condition its receiver to detect Tone A.

12.2.1.1.4 After detecting Tone A, the call modem shall transmit Tone B and condition its receiver to receive INFOh. After receiving INFOh, the modem shall proceed according to 12.3.1.

12.2.1.2 Answer Modem Error Free Operation

12.2.1.2.1 During the 75 ± 5 ms silent period ending Phase 1, the answer modem shall condition its receiver to receive INFO0c and detect Tone B. After the 75 ± 5 ms silent period, the answer modem shall send INFO0a with bit 28 set to 0, followed by Tone A.

12.2.1.2.2 After receiving INFO0c, the modem shall condition its receiver to detect Tone B and receive INFO0c.

12.2.1.2.3 After Tone B is detected and Tone A has been transmitted for at least 50 ms, the answer modem shall transmit a Tone A phase reversal. Tone A is transmitted for another 10 ms after the phase reversal, and then the modem transmits silence. The modem shall then condition its receiver to detect a Tone B phase reversal.

12.2.1.2.4 After detecting the Tone B phase reversal, the answer modem shall be conditioned to receive probing signals L1 and L2.

12.2.1.2.5 The answer modem shall receive signal L1 for its 160 ms duration. The answer modem may then receive L2 for a period of time not to exceed 500 ms. The answer modem then transmits Tone A and conditions its receiver to detect Tone B.

12.2.1.2.6 After Tone B is detected, the answer modem continues transmitting Tone A for 25 ms, then sends INFOh. After sending INFOh, the modem proceeds according to 12.3.2.

12.2.1.3 Call Modem Recovery Mechanisms

12.2.1.3.1 If, in 12.2.1.1.2 or 12.2.1.1.3, Tone A is detected before correctly receiving INFO0a, or repeated INFO0a is received, the modem will repeatedly send INFO0c.

If the call modem receives INFO0a with bit 28 set to 1, it will condition itself to detect Tone A followed by a phase reversal in Tone A, complete sending the current INFO0c sequence, and then transmit Tone B. Alternatively, if the call modem detects Tone A having correctly received INFO0a, it will condition itself to detect a phase reversal in Tone A, complete sending the current INFO0c sequence, and transmit Tone B. In either case, the call modem then proceeds according to 12.2.1.1.3.

12.2.1.3.2 If, in 12.2.1.1.3, the Tone A phase reversal is not detected, the call modem continues to transmit Tone B waiting for the answer modem to transmit another phase reversal.

12.2.1.3.3 If, in 12.2.1.1.4, Tone A is not detected within 2700 ms from transmission of the Tone B phase reversal, the call modem transmits Tone B and conditions its receiver to detect Tone A followed by a phase reversal in Tone A. The modem then proceeds in accordance with 12.2.1.1.3.

12.2.1.3.4 If, in 12.2.1.1.4, INFOh is not detected within 2000 ms from the transmission of Tone B in 12.2.1.1.4, the call modem shall continue to send Tone B and condition its receiver to detect Tone A. Upon detection of Tone A, the call modem proceeds in accordance with 12.2.1.1.4.

NOTE – The call modem shall set bit 28 of the INFO0c sequence to 1 after correctly receiving the INFO0a sequence.

12.2.1.4 Answer Modem Recovery Mechanisms

12.2.1.4.1 If, in 12.2.1.2.2 or 12.2.1.2.3, Tone B is detected before correctly receiving INFO0c, or repeated INFO0c is received, the modem will repeatedly send INFO0a.

If the answer modem receives INFO0c with bit 28 set to 1, it will condition itself to detect Tone B, complete sending the current INFO0a sequence, and transmit Tone A. Alternatively, if the answer modem detects Tone B having correctly received INFO0c, it will complete sending the current INFO0a sequence, and transmit Tone A. In either case, the answer modem then proceeds according to 12.2.1.2.3.

12.2.1.4.2 If, in 12.2.1.2.4, the Tone B phase reversal is not detected within 2000 ms from the transmission of the Tone A phase reversal in 12.2.1.2.3, the answer modem conditions its receiver to detect Tone B. Upon detecting Tone B, the answer modem transmits Tone A and proceeds according to 12.2.1.2.3.

12.2.1.4.3 If, in 12.2.1.2.6, Tone B is not detected within 2000 ms from beginning of transmission of Tone A in 12.2.1.2.5, the answer modem sends INFOh, and then proceeds to Phase 3 of the half-duplex start-up.

NOTE – The answer modem shall set bit 28 of the INFO0a sequence to 1 after correctly receiving the INFO0c sequence.

12.2.2 Answer Modem as Source Modem

Figure 24 details Phase 2 procedures when the answer modem is the source modem.

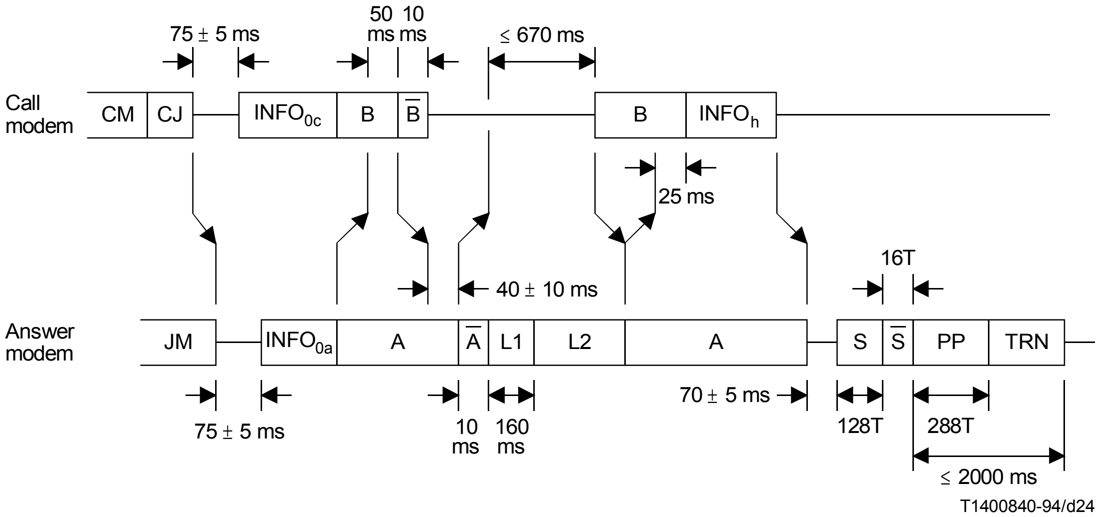


FIGURE 24/V.34

Phases 2 and 3 – Answer modem is source modem

12.2.2.1 Call Modem Error Free Operation

12.2.2.1.1 During the 75 ± 5 ms silent period ending Phase 1, the call modem shall condition its receiver to receive INFO0a and detect Tone A. After the 75 ± 5 ms silent period, the call modem shall send INFO0c with bit 28 set to 0, followed by Tone B.

12.2.2.1.2 After receiving INFO0a, the modem shall condition its receiver to detect Tone A and receive INFO0a.

12.2.2.1.3 After Tone A has been detected and Tone B has been transmitted for at least 50 ms, the call modem shall transmit a Tone B phase reversal. Tone B is transmitted for another 10 ms after the phase reversal, and then the modem transmits silence. The modem shall then condition its receiver to detect a Tone A phase reversal.

12.2.2.1.4 After detecting the Tone A phase reversal, the call modem shall be conditioned to receive probing signals L1 and L2.

12.2.2.1.5 The call modem shall receive L1 for its 160 ms duration. The call modem may then receive L2 for a period of time not to exceed 500 ms. The call modem then transmits Tone B and conditions its receiver to detect Tone A.

12.2.2.1.6 After Tone A is detected, the call modem continues transmitting Tone B for 25 ms, then sends INFOh. After sending INFOh, the modem proceeds according to 12.3.2.

12.2.2.2 Answer Modem Error Free Operation

12.2.2.2.1 During the 75 ± 5 ms silent period ending Phase 1, the answer modem shall condition its receiver to receive INFO0c and detect Tone B. After the 75 ± 5 ms silent period, the answer modem shall send INFO0a with bit 28 set ot 0, followed by Tone A.

12.2.2.2.2 After receiving INFO0c, the modem shall condition its receiver to detect Tone B and the subsequent Tone B phase reversal.

12.2.2.2.3 After detecting the Tone B phase reversal, the answer modem shall wait 40 ± 10 ms and transmit a Tone A phase reversal. Tone A shall be transmitted for another 10 ms after the phase reversal, and then the modem shall transmit signal L1 for 160 ms. The modem shall then transmit signal L2 and condition its receiver to detect Tone B.

12.2.2.2.4 After detecting Tone B, the answer modem shall transmit Tone A and condition its receiver to receive INFOh. After receiving INFOh, the modem shall proceed according to 12.3.1.

12.2.2.3 Call Modem Recovery Mechanism

12.2.2.3.1 If, in 12.2.2.1.2 or 12.2.2.1.3, Tone A is detected before correctly receiving INFO0a, or repeated INFO0a is received, the modem will repeatedly send INFO0c.

If the call modem receives INFO0a with bit 28 set to 1, it will condition itself to detect Tone A and transmit Tone B. Alternatively, if the call modem detects Tone A having correctly received INFO0a, it will transmit Tone B. In either case, the call modem then proceeds according to 12.2.2.1.3.

12.2.2.3.2 If, in 12.2.2.1.4, the Tone A phase reversal is not detected within 2000 ms from transmission of the Tone B phase reversal in 12.2.2.1.3, the call modem conditions its receiver to detect Tone A. Upon detecting Tone A, the call modem transmits Tone B and proceeds according to 12.2.2.1.3.

12.2.2.3.3 If, in 12.2.2.1.6, the Tone A phase reversal is not detected within 2000 ms from transmission of the Tone B phase reversal in 12.2.2.1.5, the call modem sends INFOh, and then proceeds according to 12.3.2.

NOTE – The call modem shall set bit 28 of the INFO0c sequence to 1 after correctly receiving the INFO0a sequence.

12.2.2.4 Answer Modem Recovery Mechanism

12.2.2.4.1 If, in 12.2.2.2.2 or 12.2.2.2.3, Tone B is detected before correctly receiving INFO0c, or repeated INFO0c is received, the modem shall repeatedly send INFO0a.

If the answer modem receives INFO0c with bit 28 set to 1, it will condition itself to detect Tone B followed by a phase reversal in Tone B, and transmit Tone A. Alternatively, if the answer modem detects Tone B having correctly received INFO0c, it shall be conditioned to detect a phase reversal in Tone B, and transmit Tone A. In either case, the answer modem shall then proceed in accordance with 12.2.2.2.3.

12.2.2.4.2 If, in 12.2.2.2.3, the Tone B phase reversal is not detected, the answer modem shall continue to transmit Tone A while waiting for the call modem to transmit another phase reversal.

12.2.2.4.3 If, in 12.2.2.2.4, Tone B is not detected within 2700 ms from the transmission of the Tone A phase reversal in 12.2.2.2.3, the answer modem shall transmit Tone A and condition its receiver to detect Tone B followed by a phase reversal in Tone B. The modem shall then proceed in accordance with 12.2.2.2.3.

12.2.2.4.4 If, in 12.2.2.2.4, INFOh is not received within 2000 ms from the transmission of Tone A in 12.2.2.2.4, the answer modem shall continue to send Tone A and condition its receiver to detect Tone B. Upon detection of Tone B, the answer modem shall proceed in accordance with 12.2.2.2.4.

NOTE – The answer modem shall set bit 28 of the INFO0a sequence to 1 after correctly receiving the INFO0c sequence.

12.3 Phase 3 – Primary Channel Equalizer Training

Equalizer training is performed in Phase 3 of the half-duplex start-up. The description below details the procedures in the source and recipient modems (see Figures 23 and 24).

12.3.1 Source Modem

12.3.1.1 After receiving INFOh, the modem shall transmit silence for 70 ± 5 ms, then transmit signal S for 128T followed by $\overline{\text{S}}$ for 16T, followed by signal PP.

12.3.1.2 After transmitting signal PP, the source modem shall transmit signal TRN. The constellation size and duration of signal TRN are set according to the INFOh sequence received from the recipient modem.

12.3.1.3 After transmitting signal TRN, the modem proceeds to transmit and receive using the control channel according to 12.4.

12.3.2 Recipient Modem

12.3.2.1 After sending INFOh, the recipient modem transmits silence and conditions its receiver to detect S followed by $\overline{S}$.

12.3.2.2 After signal S followed by $\overline{S}$ is detected, the modem conditions its receiver to begin training its main channel equalizer using signal PP. After receiving signal PP, the modem may further refine its equalizer using signal TRN.

12.3.2.3 After receiving TRN for the duration indicated in INFOh, the modem proceeds to transmit and receive using the control channel according to 12.4.

12.3.3 Recipient Modem Error Recovery Procedures

If, in 12.3.2.2, signal S is not detected within 2000 ms, the recipient modem conditions its receiver to detect Tone B. Upon detection of Tone B, the recipient modem shall transmit Tone A and proceed in accordance with 12.2.1.2.6, if it is the answer modem or 12.2.2.1.6, if it is the call modem.

12.4 Control Channel Start-up

The purpose of the control channel is to exchange information before and between the transmission of primary channel user data. Figure 25 shows the procedures for initial training of the control channel and for restarting the control channel when the source modem requests a change. Figure 26 shows the restart procedure when the recipient modem requests a change.

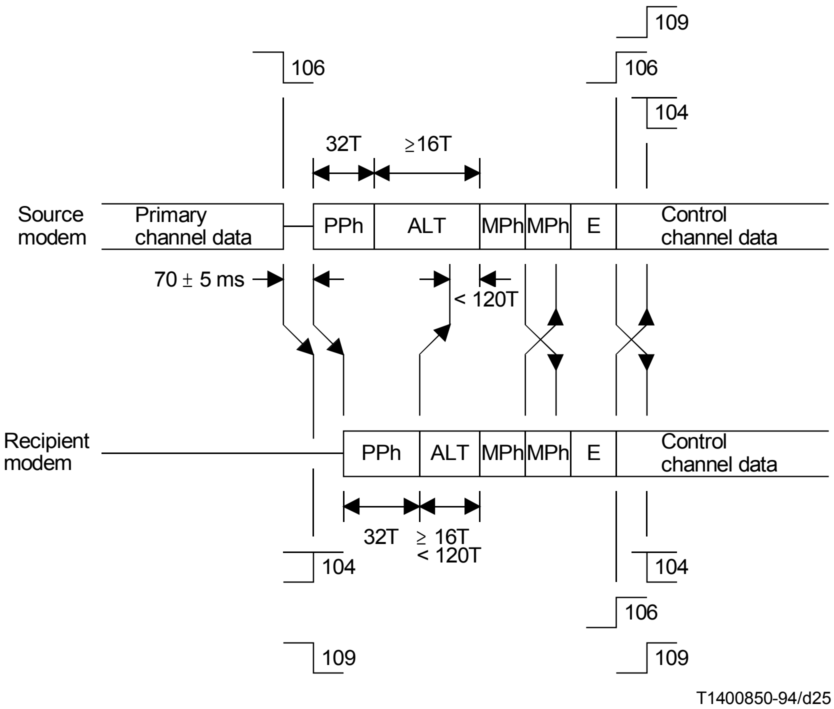


FIGURE 25/V.34

Control channel initial training and restart when siurce modem request change

12.4.1 Source Modem

12.4.1.1 The source modem shall condition its receiver to detect signal PPh. After a silent interval of 70 ± 5 ms, it sends signal PPh followed by signal ALT for a minimum of 16T. Upon detection of signal PPh, the source modem shall train its control channel equalizer using signal PPh, and condition its receiver to receive MPh from the recipient modem.

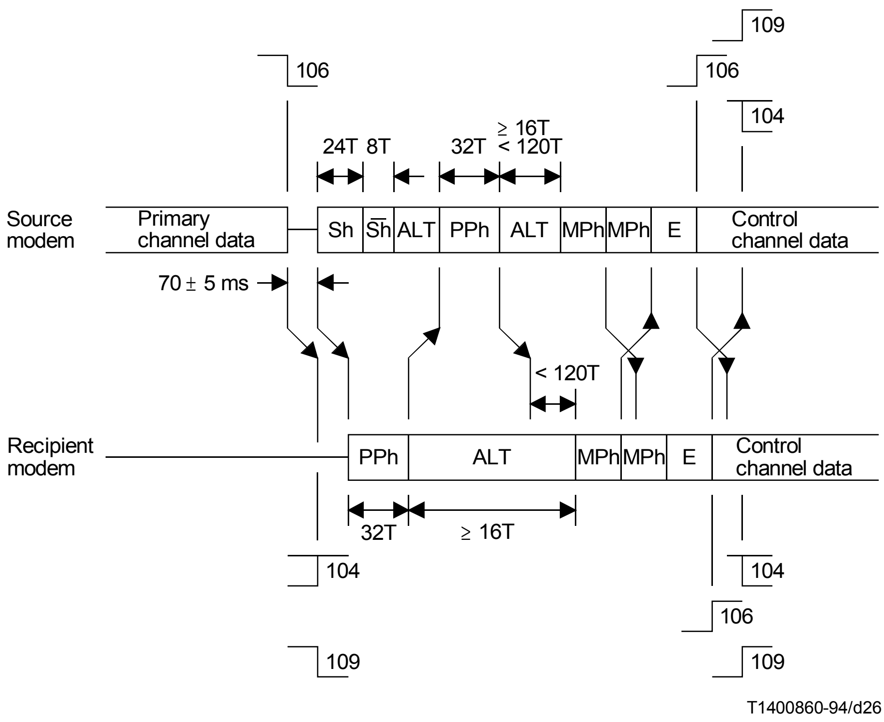


FIGURE 26/V.34

Control channel restart when recipient modem requests change

12.4.1.2 After receiving signal PPh, the source modem shall send sequence MPh within 120T.

12.4.1.3 When the source modem has received at least one MPh sequence and the modem is sending MPh sequences, the modem shall complete the current MPh and send a single 20-bit E sequence. At this time the modem shall determine the data signalling rate for the primary channel as follows:

The source modem's transmit rate shall be the maximum rate enabled that is less than or equal to the data signalling rates specified in both modems' MPh sequences.

12.4.1.4 After sending sequence E, the source modem shall enable circuit 106 to respond to circuit 105 and transmit user control channel data using the data signalling rate indicated in the MPh sequence transmitted by the recipient modem. After receiving sequence E, the modem shall unclamp circuit 104, turn on circuit 109, and receive control channel user data at the data signalling rate indicated in the MPh sequence sent by the source modem.

12.4.2 Recipient Modem

12.4.2.1 The recipient modem conditions its receiver to detect signal PPh. After detecting signal PPh, it shall transmit signal PPh, train its control channel equalizer using signal PPh, and condition its receiver to receive MPh from the source modem.

12.4.2.2 After the recipient modem transmits signal PPh it shall transmit signal ALT.

12.4.2.3 After transmitting signal ALT for at least 16T and no more than 120T, the recipient modem sends sequence MPh.

12.4.2.4 When the recipient modem has received at least one MPh sequence and the modem is sending MPh sequences, the modem shall complete the current MPh and send a single 20-bit E sequence. At this point the modem shall determine the data signalling rate for the primary channel as follows:

The recipient modem's receive rate shall be the maximum rate enabled that is less than or equal to the data signalling rates specified in both modems' MPh sequences.

12.4.2.5 After sending sequence E, the recipient modem shall enable circuit 106 to respond to circuit 105 and transmit user control channel data using the data signalling rate indicated in the MPh sequence transmitted by the source modem. After receiving E, the modem shall unclamp circuit 104, turn on circuit 109, and receive control channel user data using the data signalling rate indicated in the MPh sequence sent by the recipient modem.

12.5 Primary Channel Resynchronization Procedure

12.5.1 Source Modem

The source modem shall first transmit 70 ± 5 ms of silence, then signal S for 128T, followed by $\overline{S}$ for 16T, then signal PP followed by sequence B1. The modem shall then enable circuit 106 to respond to the condition of circuit 105 and then transmit user data.

12.5.2 Recipient Modem

The recipient modem shall first condition its receiver to detect S and $\overline{S}$, and then resynchronize its receiver using signal PP. After receiving sequence B1, the modem shall unclamp circuit 104, turn on circuit 109, and begin receiving user data.

12.5.3 Primary Channel Turn-off

12.5.3.1 Source Modem

When the source modem is in the primary channel mode and detects the ON to OFF transition of circuit 105, the modem shall turn OFF circuit 106, transmit 35 ms of scrambled ones, and then proceed according to 12.6.1.1.

12.5.3.2 Recipient Modem

When the recipient modem is in the primary channel mode and detects the OFF to ON transition of circuit 105, the modem shall turn OFF circuit 109 and clamp circuit 104, then proceed according to 12.6.2.

If the received signal level falls below the turn-off threshold as defined in 6.6.2, then the modem shall turn OFF circuit 109 and clamp circuit 104. If the received signal level returns above the turn-on threshold defined in 6.6.2, the modem shall turn ON circuit 109 and unclamp circuit 104.

12.6 Control Channel Resynchronization Procedure

Figure 27 shows the control channel resynchronization procedure that is used between page transmissions.

12.6.1 Source Modem

12.6.1.1 If a change in modulation parameters is desired, the source modem proceeds according to 12.4.1.1. Otherwise, the source modem shall transmit silence for 70 ± 5 ms, then transmit signal Sh for 24T followed by $\overline{Sh}$ for 8T.

12.6.1.2 The source modem shall then condition its receiver to detect signal PPh or signal Sh followed by $\overline{Sh}$, and then send sequence ALT.

12.6.1.3 If signal PPh is detected, the modem shall transmit signal PPh followed by sequence ALT for a minimum of 16T, condition its receiver to receive MPh, and then proceed in accordance with 12.4.1.2.

12.6.1.4 If signal Sh followed by $\overline{Sh}$ is detected, the modem shall condition its receiver to detect sequence E, and then send sequence ALT for a minimum of 16T but no more than 120T, followed by sequence E. The modem shall then enable circuit 106 to respond to the condition of circuit 105 and transmit user control channel data using the control channel data signalling rate from the previous transmission. After receiving sequence E, the modem shall unclamp circuit 104, turn on circuit 109, and receive user control channel data.

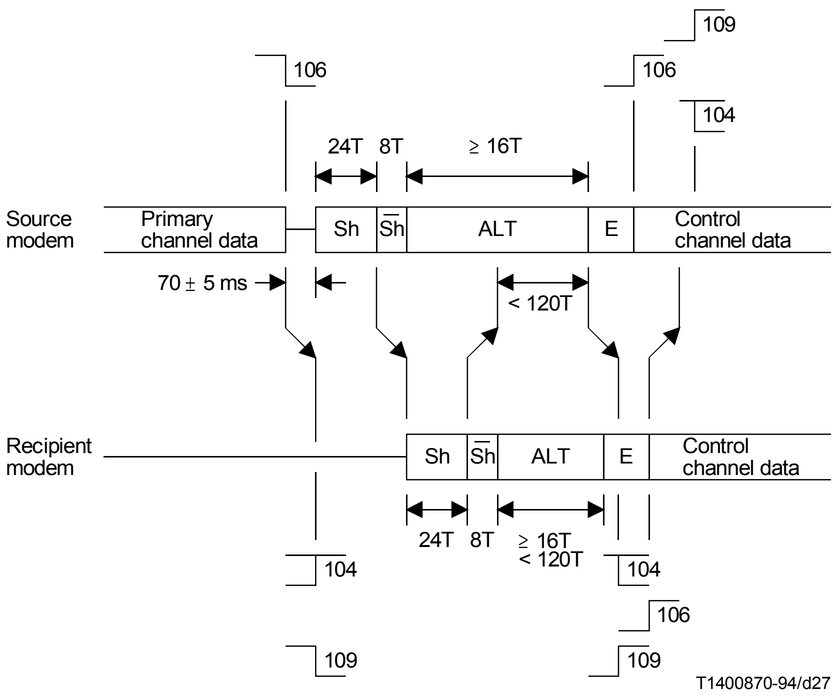


FIGURE 27/V.34

Control channel resynchronization – Normal between page signalling

12.6.2 Recipient Modem

12.6.2.1 The modem shall condition its receiver to detect signal PPh or signal Sh followed by $\overline{\text{Sh}}$. If signal PPh is detected, the modem shall send signal PPh, condition its receiver to receive sequence MPh, and proceed according to 12.4.2.2.

If signal Sh followed by $\overline{\text{Sh}}$ is detected and no change in modulation parameters is desired, the modem transmits sequence Sh for 24T, $\overline{\text{Sh}}$ for 8T, and then sends ALT for a minimum of 16T but no more than 120T, followed by sequence E. The modem shall then enable circuit 106 to respond to circuit 105 and transmit user control channel data using the control channel data signalling rate from the previous transmission. After receiving sequence E, the modem shall unclamp circuit 104, turn on circuit 109, and receive user control channel data.

If signal Sh followed by $\overline{\text{Sh}}$ is detected, and changes in modulation parameters are desired, the modem shall transmit signal PPh followed by sequence ALT, and condition its receiver to detect PPh. After PPh is detected, the modem shall proceed in accordance with 12.4.2.3.

12.6.3 Control Channel Turn-off

12.6.3.1 Source Modem

When the source modem is in the control channel mode and detects the ON to OFF transition of circuit 105, the modem shall turn OFF circuit 106, transmit 4T of scrambled ones, and then proceed according to 12.5.1.

If the received signal level falls below the turn-off threshold as defined in 6.6.2, then the modem shall turn OFF circuit 109 and clamp circuit 104. If the received signal level returns above the turn-on threshold defined in 6.6.2, the modem shall turn ON circuit 109 and unclamp circuit 104.

12.6.3.2 Recipient Modem

When the recipient modem is in the control channel mode and detects the ON to OFF transition of circuit 105, the modem shall turn OFF circuit 106, transmit 4T of scrambled ones, then transmit silence and proceed according to 12.5.2.

If the received signal level falls below the turn-off threshold as defined in 6.6.2, then the modem shall turn OFF circuit 109 and clamp circuit 104. If the received signal level returns above the turn-on threshold defined in 6.6.2, the modem shall turn ON circuit 109 and unclamp circuit 104.

12.7 Primary Channel Retrains

Figure 28 shows the control channel retrain procedure.

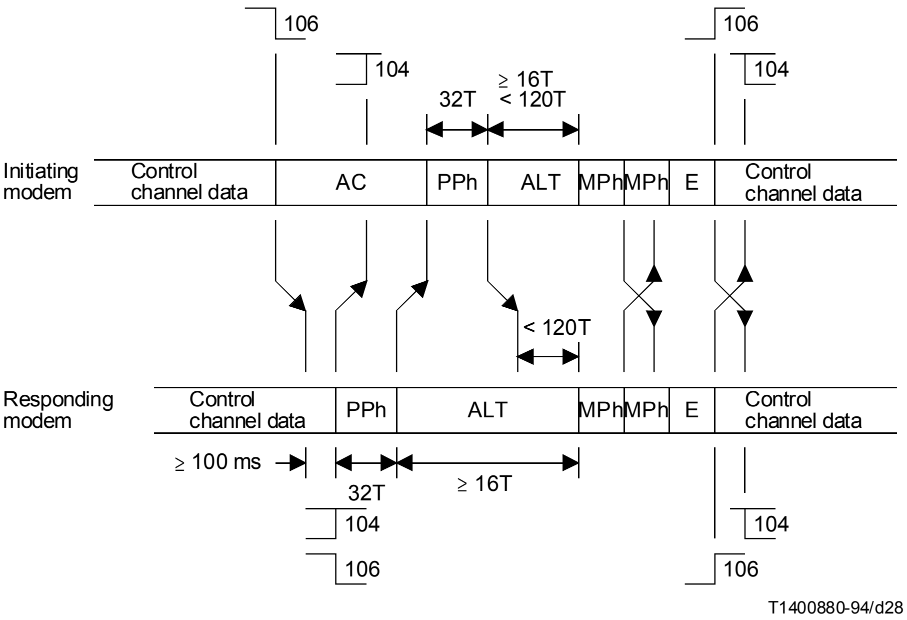


FIGURE 28/V.34

Control channel retrains

12.7.1 Call Modem – Source or Recipient

12.7.1.1 Initiating Retrain – To initiate a retrain, the call modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The call modem shall then transmit Tone B and condition its receiver to detect Tone A. After detecting Tone A, the call modem shall condition its receiver to detect a Tone A phase reversal and proceed in accordance with 12.2.1.1.3 (source modem) and 12.2.2.1.3 (recipient modem).

12.7.1.2 Responding to Retrain – After detecting Tone A for more than 50 ms, the call modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The call modem shall then transmit Tone B, condition its receiver to detect a Tone A phase reversal, and proceed in accordance with 12.2.1.1.3 (source modem) and 12.2.2.1.3 (recipient modem).

12.7.2 Answer Modem – Source or Recipient

12.7.2.1 Initiating Retrain – To initiate a retrain, the answer modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The answer modem shall then transmit Tone A, condition its receiver to detect Tone B, and proceed in accordance with 12.2.2.2.3 (source modem) and 12.2.1.2.3 (recipient modem).

12.7.2.2 Responding to Retrain – After detecting Tone B for more than 50 ms, the answer modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The answer modem shall then transmit Tone A and proceed in accordance with 12.2.2.2.3 (source modem) and 12.2.1.2.3 (recipient modem).

12.8 Control Channel Retrains

12.8.1 Initiating Retrain

To initiate a control channel retrain, the initiating modem shall turn OFF circuit 106, transmit signal AC, and condition its receiver to detect signal PPh. When signal PPh is detected, the modem shall clamp circuit 104 to binary one, condition its receiver to receive MPh and transmit signal PPh followed by sequence ALT for a minimum of 16T. The modem shall then proceed in accordance with 12.4.1.2 (source modem) or 12.4.2.3 (recipient modem).

12.8.2 Responding to Retrain

After detecting signal AC for more than 100 ms, the responding modem shall turn OFF circuit 106, clamp circuit 104 to binary one, and proceed in accordance with 12.4.1.1 (source modem) or 12.4.2.1 (recipient modem).

13 Testing Facilities

Test loops 2 and 3 as defined in Recommendation V.54 shall be provided. Provision for test loop 2 shall be as specified for point-to-point circuits. Test loop 2 need only be supported for symmetric data signalling rates.

14 Glossary

14.1 Variables and Parameters used in Data mode (clauses 5 to 9)

a	A parameter in the symbol rate definition
b	Number of bits in a high mapping frame
c	A parameter in the symbol rate definition
c(n)	An input to trellis encoder
d	A parameter in the carrier frequency definition
e	A parameter in the carrier frequency definition
f	Frequency in Hz
$g_2(p)$	Generating function used in shell mapper
h(p)	Precoding coefficients
i	Mapping frame index
j	A cyclic 4D symbol interval index
k	A cyclic 2D symbol interval index
m	A 4D symbol interval index
$m_{i,j,k}$	A ring index
n	A 2D symbol interval index
p(n)	Rounded precoder filter output
q(n)	Precoder filter output
q	A parameter used in mapping
r	A parameter used in mapping frame switching
s	Subset label in trellis encoder
u	Precoder input signal
v	A signal point from the quarter-constellation
w	A parameter in precoding

$x(n)$	Non-linear encoder input signal
$x'(n)$	Non-linear encoder output signal
$y(n)$	An input to trellis encoder
$z_8(p)$	A cumulative function used in shell mapping
A-H	Variables used in shell mapping
C_0	Modulo encoder output
I	A data bit
$I(m)$	Differential encoder input
J	Number of data frames per superframe
K	Number of shell mapping input bits
L	Number of 2D signal constellation points
M	Number of rings in shell mapping
N	Number of data bits per data frame
P	Number of mapping frames per data frame
Q	A signal point label
$Q_{i,j,k,1}$	A data bit
R	Aggregate data signalling rate
R_{0-5}	Shell mapping variables
S	Symbol Rate
$S_{i,1}$	Shell mapping input bit
T	Symbol interval
U_0	Trellis encoder output
V_0	A bit inversion signal
W	Number of auxiliary channel bits per data frame
$Y_0(m)$	Convolutional encoder output
$Y_{1-4}(m)$	Convolutional encoder inputs
Z	Differential encoder output
α, β, γ	Parameters used in pre-emphasis filter definitions
ζ	A variable used in non-linear encoder
Φ	A variable used in non-linear encoder
Θ	A parameter used in non-linear encoder

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EXHIBIT G

INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

V.92
(11/2000)

SERIES V: DATA COMMUNICATION OVER THE TELEPHONE NETWORK

Simultaneous transmission of data and other signals

Enhancements to Recommendation V.90

ITU-T Recommendation V.92

(Formerly CCITT Recommendation)

ITU-T V-SERIES RECOMMENDATIONS

DATA COMMUNICATION OVER THE TELEPHONE NETWORK

For further details, please refer to the list of ITU-T Recommendations.

ITU-T Recommendation V.92

Enhancements to Recommendation V.90

Summary

Digital and analogue modems for use on the Public Switched Telephone Network (PSTN) at data signalling rates up to 56 000 bit/s downstream and up to 48 000 bit/s upstream, with reduced start-up time on recognized connections, and procedures to support modem-on-hold in response to call-waiting events or outgoing call requests.

Source

ITU-T Recommendation V.92 was prepared by ITU-T Study Group 16 (2001-2004) and approved under the WTSA Resolution 1 procedure on 17 November 2000.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

CONTENTS

ITU-T Recommendation V.92

Enhancements to Recommendation V.90

1 Scope

This Recommendation specifies the operation between two different modems, one a digital modem and the other an analogue modem, both as defined in clause 3. The two modems are specified herein in terms of coding, start-up signals and sequences, operating procedures and DTE-DCE interface functionality. The network interface of the digital modem and the signalling rate that is used to connect the digital modem locally to a digital switched network are considered to be national matters and are hence not specified herein. The principal characteristics of these modems are as follows:

a) duplex mode of operation on the PSTN;

b) channel separation by echo cancellation techniques;

c) PCM modulation in both directions at a symbol rate of 8000;

d) synchronous channel data signalling rates in the downstream direction from 28 000 bit/s to 56 000 bit/s in increments of 8000/6 bit/s;

e) synchronous channel data signalling rates in the upstream direction from 24 000 bit/s to 48 000 bit/s in increments of 8000/6 bit/s;

f) adaptive techniques that enable the modems to achieve close to the maximum data signalling rates the channel can support on each connection;

g) negotiate V.34 modulation upstream (downstream) if a connection will not support PCM modulation upstream (downstream);

h) exchange of rate sequences during start-up to establish the data signalling rate;

i) use of V.8, and optionally V.8 *bis*, procedures during modem start-up or selection;

j) reduced start-up time on recognized connections; and

k) support of modem-on-hold procedures in response to call-waiting events or outgoing call requests.

2 References

The following ITU-T Recommendations and other references contain provisions, which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

– ITU-T G.711 (1988), *Pulse code modulation (PCM) of voice frequencies.*

– ITU-T V.8 (2000), *Procedures for starting sessions of data transmission over the public switched telephone network.*

– ITU-T V.8 *bis* (2000), *Procedures for the identification and selection of common modes of operation between data circuit-terminating equipment (DCEs) and between data terminal equipment (DTEs) over the public switched telephone network and on leased point-to-point telephone-type circuits.*

- ITU-T V.14 (1993), *Transmission of start-stop characters over synchronous bearer channels.*
- ITU-T V.21 (1988), *300 bits per second duplex modem standardized for use in the general switched telephone network.*
- ITU-T V.24 (2000), *List of definitions for interchange circuits between data terminal equipment (DTE) and data circuit-terminating equipment (DCE).*
- ITU-T V.25 (1996), *Automatic answering equipment and general procedures for automatic calling equipment on the general switched telephone network including procedures for disabling of echo control devices for both manually and automatically established calls.*
- ITU-T V.34 (1998), *A modem operating at data signalling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits.*
- ITU-T V.42 (1996), *Error-correcting procedures for DCEs using asynchronous-to-synchronous conversion.*
- ITU-T V.43 (1998), *Data flow control.*
- ITU-T V.80 (1996), *In-band DCE control and synchronous data modes for asynchronous DTE.*
- ITU-T V.90 (1998), *A digital modem and analogue modem pair for use on the public switched telephone network (PSTN) at data signalling rates of up to 56 000 bit/s downstream and up to 33 600 bit/s upstream.*

3 Definitions

This Recommendation defines the following terms:

3.1 analogue modem: The analogue modem is the modem of the pair that, when in data mode, receives G.711 signals that have been passed through a G.711 decoder. The modem is typically connected to the PSTN.

3.2 digital modem: The digital modem is the modem of the pair that, when in data mode, generates G.711 signals. The modem is connected to a digital switched network through a digital interface, e.g. a Basic Rate Interface (BRI) or a Primary Rate Interface (PRI).

3.3 downstream: Transmission in the direction from the digital modem towards the analogue modem.

3.4 nominal transmit power: Reference transmit power that is configured by the user.

3.5 Qa.b format: Numbers denoted as signed Qa.b are represented in (a + b + 1)-bit two's-complement format with b bits after the binary point, and assume values in the half-open interval $[-2^a, 2^a[$. Numbers denoted as unsigned Qa.b are represented in (a + b)-bit format with b bits after the binary point, and assume values in the half-open interval $[0, 2^{a+1}[$.

3.6 Ucode: As defined in clause 3/V.90.

3.7 upstream: Transmission in the direction from the analogue modem towards the digital modem.

3.8 L_U: The value of L_U is set such that TRN_{1U} is transmitted at the desired data mode transmit power.

4 Abbreviations

This Recommendation uses the following abbreviations:

BRI	Basic Rate Interface
DCE	Data Circuit-Terminating Equipment
DIL	Digital Impairment Learning sequence
DTE	Data Terminal Equipment
PRI	Primary Rate Interface
PSTN	Public Switched Telephone Network
RTDEd	Round-Trip Delay Estimate – digital modem

5 Digital modem

The data signalling rates, symbol rate, scrambler and encoder for the digital modem shall be the same as those given in clause 5/V.90.

6 Analogue modem

6.1 Data signalling rates

The modem shall transmit synchronously at data signalling rates of 24 000 bit/s to 48 000 bit/s in increments of 8000/6 bit/s. The data signalling rate shall be determined during Phase 4 of modem start-up according to the procedures described in 9.6.

6.2 Symbol rate

The upstream symbol rate shall be 8000 symbol/s derived from the digital network.

6.3 Scrambler

The analogue modem shall include a self-synchronizing scrambler as specified in clause 7/V.34, using the generating polynomial, GPA, in equation 7-2/V.34.

6.4 Transmitter

The framing of the transmitter shall be based upon Figure 1.

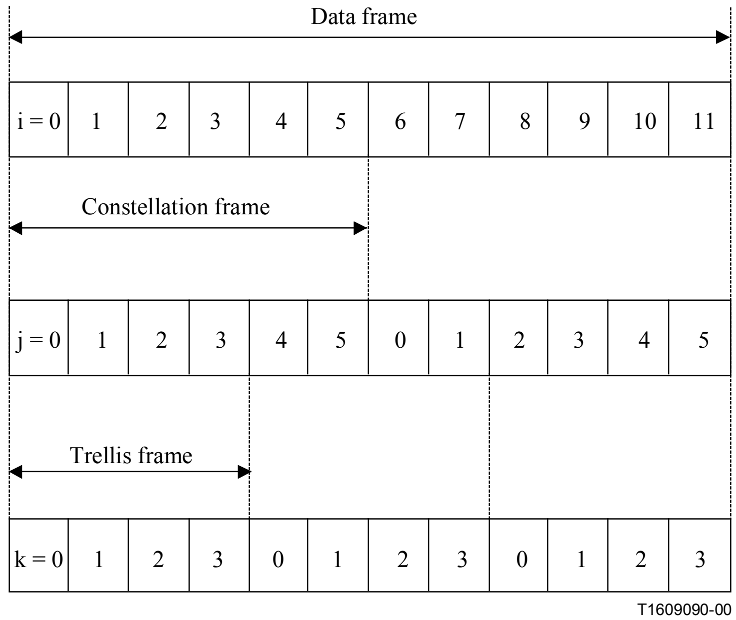


Figure 1/V.92 – Framing structure for the analogue modem

Figure 2 is a block diagram of the major elements of the analogue modem transmitter, which are described in detail in 6.4.1 to 6.4.4.

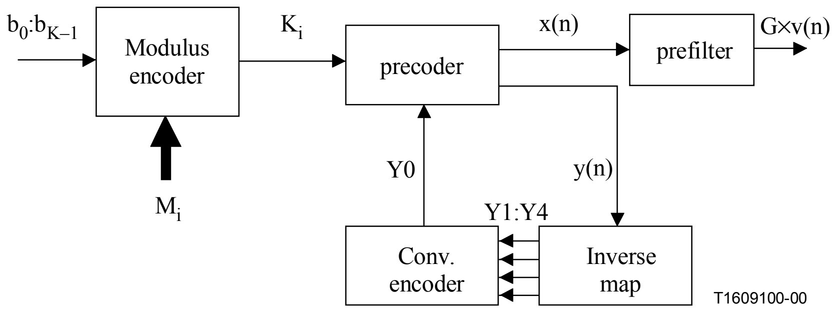


Figure 2/V.92 – Analogue modem transmitter block diagram

6.4.1 Modulus encoder

For each data frame, K scrambled bits, denoted by bits b_0 to b_{K-1}, where b_0 is first in time, enter the modulus encoder. Parameters M_0 to M_{11} also enter the modulus encoder.

The values of M_i and K shall satisfy the inequality $2^K \le M = \prod_{i=0}^{11} M_i$

The modulus encoder converts the K bits into twelve numbers, K_0 to K_{11}, using the following algorithm.

NOTE – Other implementations are possible but the mapping function must be identical to that given in the algorithm described below.

1) Represent the incoming K bits as an integer, R:

$$R = b_0 + b_1 \times 2^1 + \ldots + b_{K-1} \times 2^{K-1}$$

2) Determine the 'sign' of R:

$$s(f) = 0 \text{ if } R \le (M-1)/2;\ s(f) = 1 \text{ if } R > (M-1)/2$$

3) Differentially encode the 'sign':

$$d(f) = s(f) \oplus d(f-1), \text{ where } \oplus \text{ represents modulo 2 addition}$$

4) Form R_0:

$$R_0 = R \text{ if } d(f-1) = 0;\ R_0 = M - 1 - R \text{ if } d(f-1) = 1$$

5) Divide R_0 by M_0. The remainder of this division gives K_0, the quotient becomes R_1 for use in the calculation for the next data frame interval. Continue for the remaining eleven data frame intervals. This gives K_0 to K_{11} as:

$$K_i = R_i \text{ modulo } M_i, \text{ where } 0 \le K_i < M_i;\ R_{i+1} = (R_i - K_i)/M_i$$

6) The numbers K_0 to K_{11} are the outputs of the modulus encoder, where K_0 corresponds to data frame interval 0 and K_{11} corresponds to data frame interval 11.

6.4.2 Precoder and prefilter

The precoder has inputs from the modulus encoder and the convolutional encoder. For each K_i received from the modulus encoder, the precoder identifies K_i with an equivalence class $E(K_i)$. The precoder selects a point u(n) from the equivalence class $E(K_i)$. The index of the constellation point u(n) is denoted by y(n).

The equivalence classes are chosen as follows. Let the N constellation points be denoted by $a(\eta)$, $-N/2 \le \eta < N/2$, where the indices are in the same order as the levels. (N is the appropriate constellation length taken from the CP_d sequence, i.e. one of $2*LC_1$ through $2*LC_6$ in Table 30). Thus negative points have negative indices, and positive points have non-negative indices. The modulus encoder output K_i has M_i possible values $0 \le K_i < M_i$. The equivalence class $E(K_i)$ corresponding to K_i is then defined as:

$$E(K_i) = \{a(\eta_k) \mid \eta_k = K_i + z_k M_i,\ z_k \text{ an integer}\} \text{ for } k = 0, 1, 2;$$

$$\{a(\eta_k) \mid \eta_k = 2K_i + 2z_k M_i + (\eta_0 + \eta_1 + \eta_2 + Y0)\text{mod}2,\ z_k \text{ an integer}\} \text{ for } k = 3.$$

The precoder filter output is then:

$$x(n) = u(n) + \sum_{\kappa=1}^{LZ_1} u(n-\kappa) z_1(\kappa) + \sum_{\kappa=1}^{LP_1} x(n-\kappa) p_1(\kappa)$$

The prefilter takes the output of the precoder filter and produces v(n), defined as:

$$v(n) = \sum_{\kappa=0}^{LZ_2-1} x(n-\kappa) z_2(\kappa) + \sum_{\kappa=1}^{LP_2} v(n-\kappa) p_2(\kappa)$$

Finally the output v(n) is multiplied by a gain, G.

6.4.3 Inverse map

For each trellis frame the inverse map takes the two pairs (y(0),y(1)) and (y(2),y(3)) and produces Y1, Y2, Y3 and Y4. It is identical to the symbol-to-bit converter described in 9.6.3.1/V.34. The odd-integer coordinates used in 9.6.3.1/V.34 are calculated as $2 \times y(k) + 1$.

6.4.4 Convolutional encoder

The convolutional encoders from ITU-T V.34 shall be used. The convolutional encoder takes the outputs Y1, Y2, Y3 and Y4 from the inverse map and produces Y0, as described in 9.6.3.2/V.34, except that the 2T delays are replaced by 4T delays.

7 Interchange circuits

The requirements of this clause apply to both modems.

7.1 List of interchange circuits

References in this Recommendation to V.24 interchange circuit numbers are intended to refer to the functional equivalent of such circuits and are not intended to imply the physical implementation of such circuits. For example, references to circuit 103 should be understood to refer to the functional equivalent of circuit 103 (see Table 1).

Table 1/V.92 – Interchange circuits

Interchange circuit		Notes
No.	Description	
102	Signal ground or common return	
103	Transmitted data	
104	Received data	
105	Request to send	
106	Ready for sending	
107	Data set ready	
108/1 or	Connect data set to line	
108/2	Data terminal ready	
109	Data channel received line signal detector	1
125	Calling indicator	
133	Ready for receiving	2
NOTE 1 – Thresholds and response times are not applicable because a line signal detector cannot be expected to distinguish received signals from talker echoes.		
NOTE 2 – Operation of circuit 133 shall be in accordance with 4.2.1.1/V.43.		

7.2 Asynchronous character-mode interfacing

The modem may include an asynchronous-to-synchronous converter interfacing to the DTE in an asynchronous (or start-stop character) mode. The protocol for the conversion shall be in accordance with ITU-T V.14, ITU-T V.42 or ITU-T V.80. Data compression may also be employed.

8 Signals and sequences

All PCM codewords transferred in training sequences are described using the universal codes as specified in Table 1/V.90. In Tables 2 to 5, 11 to 24, 27 and 30 to 33, unless stated otherwise, values given as bit patterns are transmitted leftmost bit first in time and values given as integers are transmitted least-significant bit first in time.

8.1 Full Phase 1

All full Phase 1 signals and sequences are defined in ITU-T V.25, ITU-T V.8 or ITU-T V.8 *bis*.

8.2 Short Phase 1 signals and sequences for the analogue modem

Signals QC1a and QCA1a are intended for use when the connection is initiated according to ITU-T V.8. Signals QC2a and QCA2a are intended for use when the connection is initiated according to ITU-T V.8 *bis*.

Short Phase 1 information bits are transmitted at 300 bits/s modulating either V.21(L), the low-band channel defined in ITU-T V.21, or ITU-T V.21(H), the high-band channel defined in ITU-T V.21.

8.2.1 QC1a

Signal QC1a is a sequence of bits transmitted using V.21(L) modulation. The sequence consists of 10-bit frames using V.8-type formatting as defined in Table 2. QC1a is transmitted once, and is followed immediately by CM.

Table 2/V.92 – Definition of QC1a

<table>
<tr><th>Bit position</th><th>Content</th><th colspan="2">Definition</th></tr>
<tr><td>0:9</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
<tr><td>10:19</td><td>0101010101</td><td colspan="2">Synchronization sequence</td></tr>
<tr><td>20</td><td>0</td><td colspan="2">Start bit</td></tr>
<tr><td>21</td><td>0</td><td colspan="2">Indication for analogue modem</td></tr>
<tr><td>22</td><td>0</td><td colspan="2">Indication for QC</td></tr>
<tr><td>23</td><td>P</td><td colspan="2">Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)</td></tr>
<tr><td>24:29</td><td>W0XYZ1</td><td>WXYZ</td><td>U_{QTS}: Ucode of the PCM codeword to be used for QTS</td></tr>
<tr><td colspan="2" rowspan="16"></td><td>0000</td><td>61</td></tr>
<tr><td>0001</td><td>62</td></tr>
<tr><td>0010</td><td>63</td></tr>
<tr><td>0011</td><td>66</td></tr>
<tr><td>0100</td><td>67</td></tr>
<tr><td>0101</td><td>70</td></tr>
<tr><td>0110</td><td>71</td></tr>
<tr><td>0111</td><td>74</td></tr>
<tr><td>1000</td><td>75</td></tr>
<tr><td>1001</td><td>78</td></tr>
<tr><td>1010</td><td>79</td></tr>
<tr><td>1011</td><td>82</td></tr>
<tr><td>1100</td><td>83</td></tr>
<tr><td>1101</td><td>86</td></tr>
<tr><td>1110</td><td>87</td></tr>
<tr><td>1111</td><td>Cleardown from on-hold state</td></tr>
<tr><td>30:39</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
<tr><td>40:49</td><td>0101010101</td><td colspan="2">Bits 10:19 repeated</td></tr>
<tr><td>50:59</td><td>000PW0XYZ1</td><td colspan="2">Bits 20:29 repeated</td></tr>
</table>

8.2.2 QC2a

Signal QC2a is a sequence of bits transmitted using V.21(H) modulation. The bits are transmitted using the signal structure defined in clause 7/V.8 *bis* and the information field structure defined in clause 8/V.8 *bis*. The analogue modem shall encode the identification field as defined in Table 3.

Table 3/V.92 – Definition of identification field in QC2a

Bit position	Content	Definition
0:3	1011	Message type
4:7	VVVV	V.8 *bis* revision number (Note)
8:11	WXYZ	U_{QTS} from Table 2
12	0	Reserved for ITU
13	P	Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)
14	0	QC identifier
15	0	Analogue modem
NOTE – At the time of publication the V.8 *bis* revision number is 0100. The receiving modem shall ignore this field.		

8.2.3 QCA1a

Signal QCA1a is a sequence of bits transmitted using V.21(H) modulation. The sequence consists of 10-bit frames using V.8-type formatting as defined in Table 4. QCA1a is transmitted once.

Table 4/V.92 – Definition of QCA1a

Bit position	Content	Definition
0:9	1111111111	Ten ONEs
10:19	0101010101	Synchronization sequence
20	0	Start bit
21	0	Indication for analogue modem
22	1	Indication for QCA
23	P	Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)
24:29	W0XYZ1	U_{QTS}: WXYZ from Table 2
30:39	1111111111	Ten ONEs
40:49	0101010101	Bits 10:19 repeated
50:59	001PW0XYZ1	Bits 20:29 repeated
60:69	1111111111	Ten ONEs

8.2.4 QCA2a

Signal QCA2a is a sequence of bits transmitted using V.21(L) modulation. The bits are transmitted using the signal structure defined in clause 7/V.8 *bis* and the information field structure defined in clause 8/V.8 *bis*. The analogue modem shall encode the identification field as defined in Table 5.

Table 5/V.92 – Definition of identification field in QCA2a

Bit position	Content	Definition
0:3	`1011`	Message type
4:7	`VVVV`	V.8 *bis* revision number (Note)
8:11	`WXYZ`	U_{QTS} from Table 2
12	`0`	Reserved for ITU
13	`P`	Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)
14	`1`	QCA identifier
15	`0`	Analogue modem
NOTE – At the time of publication the V.8 *bis* revision number is 0100. The receiving modem shall ignore this field.		

8.2.5 TONEq

Signal TONEq is a 980 Hz tone.

8.3 Short Phase 1 signals and sequences for the digital modem

Signals QC1d and QCA1d are intended for use when the connection is initiated according to ITU-T V.8. Signals QC2d and QCA2d are intended for use when the connection is initiated according to ITU-T V.8 *bis*.

8.3.1 ANSpcm

Signal ANSpcm is a repetitive sequence of PCM codewords that produces a tone at approximately 2100 Hz. The sequence repeats every 301 symbols and has a phase reversal added to it every 3612 symbols. The codeword sequence may be used to verify that assumed channel characteristics are correct, and shall be transmitted at one of four transmit levels as defined in Table 6.

Table 6/V.92 – ANSpcm generation parameters

Transmit level	scl		ϑ
	μ-law	A-law	
−9.5 dBm0	1334	667	$0.25 \times \pi / 301$
−12 dBm0	1000	500	$0.25 \times \pi / 301$
−15 dBm0	708	354	$0.25 \times \pi / 301$
−18 dBm0	500	250	$0.25 \times \pi / 301$

The 301 symbol Ucode sequence may be generated using the following equation:

$$x = \lfloor scl \times \sqrt{2} \times \cos(2\pi k \times 79 / 301 + \vartheta) + 0.5 \rfloor \text{ for } k = 0, 1, 2, \ldots, 300$$

and quantizing x to a linear PCM value according to ITU-T G.711 where scl and ϑ are defined in Table 6. The resulting output shall equal the output defined in Tables 7 to Table 10 depending on the value of scl.

NOTE – Some network equipment are known to alter the characteristics of the channel in response to ANSpcm.

Table 7/V.92 – −9.5 dBm0 ANSpcm sequence

	μ	A		μ	A		μ	A		μ	A		μ	A		μ	A		μ	A
0	A1	88	43	43	6F	86	24	0F	129	AD	87	172	AD	87	215	24	0F	258	43	6C
1	58	76	44	23	09	87	B1	98	130	A9	80	173	27	0D	216	39	10	259	A2	88
2	22	08	45	B8	93	88	A7	8D	131	29	00	174	31	18	217	A3	89	260	DC	CB
3	C2	EE	46	A5	8F	89	2C	07	132	2D	07	175	A4	8F	218	C5	ED	261	22	08
4	A3	89	47	30	1B	90	2A	00	133	A6	8D	176	BA	91	219	22	08	262	D6	F0
5	38	13	48	27	0D	91	A9	83	134	B2	99	177	23	09	220	5E	4F	263	A2	88
6	25	0F	49	AC	87	92	AD	84	135	24	0F	178	46	62	221	A2	88	264	40	69
7	B0	9B	50	AA	80	93	26	0D	136	3A	11	179	A2	88	222	53	7D	265	23	0E
8	A7	82	51	29	03	94	33	1E	137	A3	89	180	E2	C0	223	22	08	266	B7	92
9	2C	06	52	2D	04	95	A4	8F	138	C7	E3	181	22	08	224	BF	EB	267	A5	8F
10	2A	01	53	A6	8D	96	BB	96	139	22	08	182	D1	FF	225	A3	8E	268	2F	1A
11	A9	83	54	B3	9E	97	22	09	140	67	45	183	A2	89	226	37	12	269	27	02
12	AE	84	55	24	0E	98	48	60	141	A2	88	184	3F	6A	227	25	0C	270	AC	86
13	26	0C	56	3C	17	99	A2	88	142	4F	79	185	23	0E	228	AF	9A	271	AA	81
14	34	1F	57	A2	89	100	EC	DE	143	22	09	186	B6	9D	229	A8	82	272	28	03
15	A4	8E	58	CA	E6	101	22	08	144	BE	95	187	A5	8C	230	2B	06	273	2E	04
16	BC	97	59	22	08	102	CE	FA	145	A3	8E	188	2F	05	231	2B	01	274	A6	8C
17	22	09	60	72	53	103	A2	89	146	36	1D	189	28	02	232	A8	83	275	B4	9F
18	4B	67	61	A2	88	104	3E	15	147	25	0C	190	AB	86	233	AE	85	276	24	0E
19	A2	88	62	4D	65	105	23	0E	148	AF	85	191	AB	81	234	26	0C	277	3D	14
20	FC	D4	63	22	09	106	B5	9C	149	A8	82	192	28	02	235	35	1C	278	A2	89
21	22	08	64	BD	94	107	A5	8C	150	2B	01	193	2E	05	236	A4	8E	279	CC	E4
22	CB	E7	65	A4	8E	108	2E	05	151	2B	06	194	A5	8C	237	BD	94	280	22	08
23	A2	89	66	34	1F	109	28	03	152	A8	82	195	B5	9C	238	22	09	281	F7	D6
24	3C	17	67	26	0C	110	AB	81	153	AF	85	196	23	0E	239	4D	65	282	A2	88
25	24	0E	68	AE	85	111	AB	86	154	25	0C	197	3E	15	240	A2	88	283	4A	66
26	B4	9F	69	A8	83	112	28	02	155	36	1D	198	A2	89	241	6F	5D	284	22	09
27	A6	8C	70	2A	01	113	2F	05	156	A3	8E	199	CE	FB	242	22	08	285	BC	97
28	2E	04	71	2B	06	114	A5	8C	157	BF	EA	200	22	08	243	C9	E1	286	A4	8E
29	28	03	72	A7	82	115	B6	9D	158	22	09	201	EA	D8	244	A2	89	287	33	1E
30	AA	81	73	AF	9A	116	23	0E	159	50	7E	202	A2	88	245	3B	16	288	26	0C
31	AC	86	74	25	0F	117	3F	6B	160	A2	88	203	48	60	246	24	0E	289	AE	84
32	27	02	75	37	12	118	A2	89	161	65	47	204	23	09	247	B3	9E	290	A9	83
33	2F	1A	76	A3	8E	119	D2	FC	162	22	08	205	BB	96	248	A6	8D	291	2A	01
34	A5	8F	77	C0	E8	120	22	08	163	C6	E3	206	A4	8F	249	2D	04	292	2C	06
35	B8	93	78	22	08	121	E0	C2	164	A3	89	207	32	19	250	29	03	293	A7	82
36	23	0E	79	55	73	122	A2	88	165	3A	11	208	26	0D	251	AA	80	294	B0	9B
37	41	69	80	A2	88	123	45	6D	166	24	0F	209	AD	84	252	AC	87	295	25	0F
38	A2	88	81	5D	49	124	23	09	167	B2	99	210	A9	80	253	27	0D	296	38	13
39	D7	F1	82	22	8	125	BA	91	168	A6	8D	211	2A	00	254	30	1B	297	A3	89
40	21	08	83	C4	EC	126	A4	8F	169	2D	07	212	2C	07	255	A5	8F	298	C2	EE
41	DB	F5	84	A3	89	127	31	18	170	29	00	213	A7	8D	256	B9	90	299	22	08
42	A2	88	85	39	10	128	27	0D	171	A9	80	214	B1	98	257	23	09	300	59	74

Table 8/V.92 – −12 dBm0 ANSpcm sequence

	μ	A		μ	A		μ	A		μ	A		μ	A		μ	A		μ	A
0	A9	83	43	4A	66	86	2B	06	129	B3	9E	172	B3	9E	215	2B	06	258	4A	66
1	5D	49	44	2A	00	87	B8	93	130	AF	85	173	2D	07	216	3F	6A	259	A9	80
2	29	00	45	BE	95	88	AD	87	131	2F	05	174	39	10	217	AA	80	260	E0	C2
3	C9	E1	46	AB	86	89	32	19	132	33	1E	175	AB	81	218	CB	E7	261	29	03
4	AA	80	47	38	13	90	2F	1A	133	AD	87	176	BF	EB	219	29	00	262	DB	F5
5	3D	15	48	2D	07	91	AE	85	134	B9	90	177	2A	00	220	64	46	263	A9	80
6	2B	06	49	B2	99	92	B4	9F	135	2B	01	178	4C	64	221	A9	83	264	48	60
7	B7	92	50	AF	9A	93	2C	07	136	3F	6B	179	A9	80	222	59	77	265	2A	01
8	AD	84	51	2E	05	94	3A	11	137	AA	80	180	E7	DA	223	29	00	266	BD	94
9	32	19	52	34	1F	95	AB	81	138	CD	E5	181	29	03	224	C7	E3	267	AB	86
10	2F	1A	53	AC	87	96	C0	E8	139	29	00	182	D8	F6	225	AA	81	268	37	12
11	AE	85	54	BA	91	97	2A	00	140	6B	59	183	A9	80	226	3D	14	269	2D	04
12	B4	9F	55	2B	01	98	4E	7A	141	A9	83	184	46	62	227	2C	06	270	B1	98
13	2C	07	56	41	69	99	A9	80	142	56	70	185	2A	01	228	B7	92	271	B0	9B
14	3A	11	57	AA	80	100	EF	DD	143	29	00	186	BC	97	229	AD	84	272	2E	05
15	AB	81	58	CE	F8	101	29	03	144	C5	ED	187	AC	86	230	31	18	273	35	1C
16	C2	EE	59	29	03	102	D4	F2	145	AA	81	188	36	1D	231	30	1B	274	AC	87
17	29	00	60	76	51	103	A9	80	146	3C	17	189	2E	04	232	AE	84	275	BB	96
18	4F	79	61	A9	83	104	44	6C	147	2C	06	190	B1	98	233	B5	9C	276	2A	01
19	A9	83	62	52	7C	105	2A	01	148	B6	9D	191	B0	9B	234	2C	06	277	43	6F
20	FD	D4	63	29	00	106	BB	96	149	AE	84	192	2E	04	235	3B	16	278	A9	80
21	29	03	64	C3	EF	107	AC	86	150	30	1B	193	36	1D	236	AA	81	279	D1	FF
22	D0	FE	65	AA	81	108	35	1C	151	31	18	194	AC	86	237	C4	EC	280	29	03
23	A9	80	66	3B	16	109	2E	04	152	AE	84	195	BC	97	238	29	00	281	F9	D6
24	42	6E	67	2C	06	110	B0	9B	153	B6	9D	196	2A	01	239	53	7D	282	A9	83
25	2B	01	68	B5	9C	111	B1	98	154	2C	06	197	45	6D	240	A9	83	283	4F	78
26	BB	96	69	AE	84	112	2D	04	155	3C	17	198	A9	80	241	72	53	284	2A	00
27	AC	87	70	30	1B	113	36	1D	156	AA	81	199	D5	F3	242	29	03	285	C2	EE
28	35	1C	71	31	18	114	AC	86	157	C5	E2	200	29	03	243	CE	FB	286	AB	81
29	2E	05	72	AD	84	115	BC	97	158	29	00	201	ED	DF	244	AA	80	287	3A	11
30	AF	9A	73	B7	92	116	2A	01	159	57	71	202	A9	80	245	41	69	288	2C	07
31	B2	99	74	2B	06	117	46	62	160	A9	83	203	4D	65	246	2B	01	289	B4	9F
32	2D	04	75	3D	14	118	A9	80	161	69	5B	204	2A	00	247	BA	91	290	AE	85
33	37	12	76	AA	81	119	D8	F6	162	29	00	205	C0	E8	248	AC	87	291	2F	1A
34	AB	86	77	C7	E3	120	29	03	163	CC	E4	206	AB	81	249	34	1F	292	32	19
35	BD	94	78	29	00	121	E6	C4	164	AA	80	207	39	10	250	2E	05	293	AD	84
36	2A	01	79	5A	74	122	A9	80	165	3F	6B	208	2C	07	251	AF	9A	294	B8	93
37	48	60	80	A9	83	123	4B	67	166	2B	01	209	B4	9F	252	B2	99	295	2B	06
38	A9	80	81	62	40	124	2A	00	167	B9	90	210	AF	85	253	2D	07	296	3E	15
39	DC	CB	82	29	00	125	BF	EA	168	AD	87	211	2F	05	254	38	13	297	AA	80
40	29	03	83	CA	E6	126	AB	86	169	33	1E	212	33	1E	255	AB	86	298	C9	E1
41	DF	CC	84	AA	80	127	39	10	170	2F	05	213	AD	87	256	BE	95	299	29	00
42	A9	80	85	3E	15	128	2D	07	171	AF	85	214	B8	93	257	2A	00	300	5E	4F

Table 9/V.92 – −15 dBm0 ANSpcm sequence

	μ	A		μ	A		μ	A		μ	A		μ	A		μ	A		μ	A
0	AF	9A	43	4F	79	86	32	19	129	BB	96	172	BB	96	215	32	19	258	50	7E
1	63	41	44	31	18	87	BF	EA	130	B8	93	173	34	1C	216	47	63	259	AF	9B
2	30	1B	45	C6	E2	88	B5	9C	131	37	12	174	3F	6B	217	B0	9B	260	E7	C5
3	CF	F8	46	B2	99	89	3B	16	132	3B	16	175	B2	99	218	D1	FF	261	2F	1A
4	B1	98	47	3E	15	90	38	13	133	B4	9F	176	C8	E0	219	2F	1A	262	E0	C2
5	45	6D	48	35	1C	91	B7	92	134	BF	EB	177	30	1B	220	69	58	263	B0	9B
6	33	1E	49	BA	91	92	BC	97	135	32	19	178	52	7C	221	AF	9A	264	4E	7B
7	BE	95	50	B8	93	93	34	1F	136	48	60	179	AF	9A	222	5F	4C	265	31	18
8	B5	9C	51	37	12	94	40	68	137	B0	9B	180	EC	DE	223	30	1B	266	C5	ED
9	3A	11	52	3C	17	95	B2	99	138	D4	F2	181	2F	1A	224	CD	E5	267	B3	9E
10	38	13	53	B4	9F	96	C9	E1	139	2F	1A	182	DD	C9	225	B1	98	268	3E	15
11	B7	92	54	C0	E8	97	30	1B	140	6F	5D	183	B0	9B	226	44	6C	269	35	1C
12	BC	97	55	32	19	98	55	73	141	AF	9A	184	4D	65	227	33	1E	270	BA	91
13	34	1F	56	49	61	99	AF	9A	142	5C	4B	185	31	18	228	BE	95	271	B9	90
14	41	69	57	B0	9B	100	F3	D3	143	30	1B	186	C4	EC	229	B6	9D	272	36	1D
15	B2	99	58	D6	F0	101	2F	1A	144	CC	E4	187	B3	9E	230	3A	11	273	3C	17
16	CA	E6	59	2F	1A	102	DB	F5	145	B1	98	188	3D	14	231	39	10	274	B4	9F
17	30	1B	60	78	56	103	B0	9B	146	43	6F	189	36	1D	232	B6	9D	275	C2	EE
18	57	76	61	AF	9A	104	4C	64	147	33	1E	190	B9	90	233	BD	94	276	31	18
19	AF	9A	62	59	77	105	31	18	148	BD	94	191	B9	90	234	33	1E	277	4B	67
20	FD	D5	63	30	1B	106	C2	EE	149	B6	9D	192	36	1D	235	42	6E	278	B0	9B
21	2F	1A	64	CB	E7	107	B3	9E	150	39	10	193	3D	14	236	B1	98	279	D9	F7
22	D8	F6	65	B1	98	108	3D	14	151	39	10	194	B3	9E	237	CB	E7	280	2F	1A
23	B0	9B	66	42	6E	109	36	1D	152	B6	9D	195	C3	EF	238	30	1B	281	FB	D7
24	4A	66	67	34	1F	110	B9	90	153	BD	94	196	31	18	239	5A	74	282	AF	9A
25	31	19	68	BC	97	111	BA	91	154	33	1E	197	4C	64	240	AF	9A	283	57	71
26	C1	E9	69	B6	9D	112	36	1D	155	43	6F	198	B0	9B	241	76	51	284	30	1B
27	B4	9F	70	39	10	113	3D	14	156	B1	98	199	DB	F5	242	2F	1A	285	CA	E6
28	3C	17	71	3A	11	114	B3	9E	157	CC	E5	200	2F	1A	243	D6	F0	286	B2	99
29	37	12	72	B5	9C	115	C4	EC	158	30	1B	201	F0	D2	244	B0	9B	287	41	69
30	B8	93	73	BE	95	116	31	18	159	5D	48	202	AF	9A	245	49	61	288	34	1F
31	BA	91	74	33	1E	117	4D	65	160	AF	9A	203	54	72	246	32	19	289	BC	97
32	35	1C	75	44	6D	118	B0	9B	161	6D	5F	204	30	1B	247	C0	E8	290	B7	92
33	3E	15	76	B1	98	119	DE	CF	162	2F	1A	205	C8	E0	248	B4	9F	291	38	13
34	B3	9E	77	CE	FA	120	2F	1A	163	D3	FD	206	B2	99	249	3C	17	292	3A	11
35	C5	ED	78	30	1B	121	EB	D9	164	B0	9B	207	3F	68	250	37	12	293	B5	9C
36	31	18	79	5F	4D	122	AF	9A	165	48	60	208	34	1F	251	B8	93	294	BE	95
37	4E	7B	80	AF	9A	123	52	7C	166	32	19	209	BB	96	252	BB	96	295	33	1E
38	B0	9B	81	68	5A	124	30	1B	167	BF	EB	210	B7	92	253	35	1C	296	46	62
39	E2	C0	82	2F	1A	125	C7	E3	168	B4	9F	211	38	13	254	3F	6A	297	B1	98
40	2F	1A	83	D0	FE	126	B2	99	169	3B	16	212	3B	16	255	B2	99	298	CF	F9
41	E6	C4	84	B1	98	127	3F	6A	170	37	12	213	B5	9C	256	C6	E2	299	30	1B
42	B0	9B	85	47	63	128	35	1C	171	B8	93	214	BF	EA	257	31	18	300	64	46

Table 10/V.92 – −18 dBm0 ANSpcm sequence

	μ	A		μ	A		μ	A		μ	A		μ	A		μ	A		μ	A
0	B8	93	43	57	71	86	3B	16	129	C2	EE	172	C2	EE	215	3B	16	258	58	76
1	69	5B	44	39	10	87	C7	E3	130	BE	95	173	3C	17	216	4E	7A	259	B9	90
2	39	10	45	CD	E5	88	BC	97	131	3E	15	174	48	60	217	B9	90	260	EC	DE
3	D7	F1	46	BB	96	89	41	69	132	42	6E	175	BA	91	218	D9	F7	261	38	13
4	B9	90	47	47	63	90	3F	6A	133	BC	97	176	CE	FA	219	39	10	262	E7	C5
5	4C	64	48	3C	17	91	BE	95	134	C8	E0	177	39	10	220	6D	5C	263	B9	90
6	3B	16	49	C1	E9	92	C3	EF	135	3A	11	178	5A	74	221	B8	93	264	56	70
7	C6	E2	50	BF	EA	93	3C	17	136	4E	7B	179	B9	90	222	65	47	265	3A	11
8	BD	94	51	3E	15	94	48	61	137	B9	90	180	EF	DD	223	39	10	266	CC	E4
9	41	69	52	43	6F	95	BA	91	138	DB	F5	181	38	13	224	D5	F3	267	BB	96
10	3F	6A	53	BC	97	96	CF	F8	139	38	10	182	E3	C1	225	BA	91	268	46	62
11	BE	95	54	C9	E1	97	39	10	140	73	53	183	B9	90	226	4C	64	269	3D	14
12	C3	EF	55	3A	11	98	5B	4A	141	B8	93	184	54	72	227	3B	16	270	C0	E8
13	3C	17	56	4F	79	99	B8	93	142	61	40	185	3A	11	228	C6	E2	271	BF	EB
14	49	61	57	B9	90	100	F6	D1	143	39	10	186	CB	E7	229	BD	94	272	3E	15
15	BA	91	58	DC	CB	101	38	13	144	D3	FD	187	BB	96	230	40	68	273	44	6C
16	D0	FE	59	38	13	102	E0	C2	145	BA	91	188	45	6D	231	3F	6B	274	BC	97
17	39	10	60	7A	57	103	B9	90	146	4B	67	189	3D	14	232	BD	94	275	CA	E6
18	5D	49	61	B8	93	104	52	7C	147	3B	16	190	C0	E8	233	C4	EC	276	3A	11
19	B8	93	62	5F	4C	105	3A	11	148	C5	ED	191	BF	EB	234	3B	16	277	51	7F
20	FE	D5	63	39	10	106	CA	E6	149	BD	94	192	3D	14	235	4A	66	278	B9	90
21	38	13	64	D1	FF	107	BB	96	150	3F	6B	193	45	6D	236	BA	91	279	DE	CF
22	DE	CE	65	BA	91	108	44	6C	151	3F	68	194	BB	96	237	D2	FC	280	38	13
23	B9	90	66	4A	66	109	3D	14	152	BD	94	195	CB	E7	238	39	10	281	FC	D4
24	50	7E	67	3B	16	110	BF	EB	153	C5	ED	196	3A	11	239	5F	4D	282	B8	93
25	3A	11	68	C4	EC	111	C0	E8	154	3B	16	197	53	7D	240	B8	93	283	5D	48
26	CA	E6	69	BD	94	112	3D	14	155	4B	67	198	B9	90	241	78	56	284	39	10
27	BC	97	70	3F	6B	113	45	6D	156	BA	91	199	E1	C3	242	38	13	285	CF	F9
28	44	6C	71	40	68	114	BB	96	157	D3	FD	200	38	13	243	DC	CB	286	BA	91
29	3E	15	72	BD	94	115	CB	E7	158	39	10	201	F5	D0	244	B9	90	287	49	61
30	BF	EA	73	C6	E2	116	3A	11	159	62	41	202	B8	93	245	4F	79	288	3C	17
31	C1	E9	74	3B	16	117	54	72	160	B8	93	203	5B	75	246	3A	11	289	C3	EF
32	3D	14	75	4C	64	118	B9	90	161	71	52	204	39	10	247	C9	E1	290	BE	95
33	46	62	76	BA	91	119	E4	C6	162	39	10	205	CF	F8	248	BC	97	291	3F	6A
34	BB	96	77	D5	F3	120	38	13	163	DA	F4	206	BA	91	249	43	6F	292	41	69
35	CC	E4	78	39	10	121	EE	DC	164	B9	90	207	48	60	250	3E	15	293	BD	94
36	39	10	79	66	44	122	B9	90	165	4E	7B	208	3C	17	251	BF	EA	294	C6	E3
37	56	70	80	B8	93	123	59	77	166	3A	11	209	C2	EF	252	C1	E9	295	3B	16
38	B9	90	81	6D	5F	124	39	10	167	C8	E0	210	BE	95	253	3C	17	296	4D	65
39	E8	DA	82	39	10	125	CE	FA	168	BC	97	211	3E	15	254	47	63	297	B9	90
40	38	13	83	D8	F6	126	BA	91	169	42	6E	212	42	6E	255	BB	96	298	D7	F1
41	EB	D9	84	B9	90	127	47	60	170	3E	15	213	BC	97	256	CD	E5	299	39	10
42	B9	90	85	4D	65	128	3C	17	171	BE	95	214	C7	E3	257	39	10	300	6A	58

8.3.2 QC1d

Signal QC1d is a sequence of bits transmitted using V.21(L) modulation. The sequence consists of 10-bit frames using V.8-type formatting as defined in Table 11. QC1d is transmitted once, and is followed immediately by CM.

Table 11/V.92 – Definition of QC1d

<table>
<tr><th>Bit position</th><th>Content</th><th colspan="2">Definition</th></tr>
<tr><td>0:9</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
<tr><td>10:19</td><td>0101010101</td><td colspan="2">Synchronization sequence</td></tr>
<tr><td>20</td><td>0</td><td colspan="2">Start bit</td></tr>
<tr><td>21</td><td>1</td><td colspan="2">Indication for digital modem</td></tr>
<tr><td>22</td><td>0</td><td colspan="2">Indication for QC</td></tr>
<tr><td>23</td><td>P</td><td colspan="2">Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)</td></tr>
<tr><td rowspan="5">24:29</td><td rowspan="5">000LM1</td><td>LM</td><td>Level of ANSpcm</td></tr>
<tr><td>00</td><td>−9.5 dBm0</td></tr>
<tr><td>01</td><td>−12 dBm0</td></tr>
<tr><td>10</td><td>−15 dBm0</td></tr>
<tr><td>11</td><td>−18 dBm0</td></tr>
<tr><td>30:39</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
<tr><td>40:49</td><td>0101010101</td><td colspan="2">Bits 10:19 repeated</td></tr>
<tr><td>50:59</td><td>010P000LM1</td><td colspan="2">Bits 20:29 repeated</td></tr>
</table>

8.3.3 QC2d

Signal QC2d is a sequence of bits transmitted using V.21(H) modulation. The bits are transmitted using the signal structure defined in clause 7/V.8 *bis* and the information field structure defined in clause 8/V.8 *bis*. The digital modem shall encode the identification field as defined in Table 12.

Table 12/V.92 – Definition of identification field in QC2d

Bit position	Content	Definition
0:3	1011	Message type
4:7	VVVV	V.8 *bis* revision number (Note)
8:9	LM	Level of ANSpcm from Table 11
10:12	000	Reserved for the ITU
13	P	Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)
14	0	QC identifier
15	1	Digital modem
NOTE – At the time of publication the V.8 *bis* revision number is 0100. The receiving modem shall ignore this field.		

8.3.4 QCA1d

Signal QCA1d is a sequence of bits transmitted using V.21(H) modulation. The sequence consists of 10-bit frames using V.8-type formatting as defined in Table 13. QCA1d is transmitted once.

Table 13/V.92 – Definition of QCA1d

<table>
<tr><th>Bit position</th><th>Content</th><th colspan="2">Definition</th></tr>
<tr><td>0:9</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
<tr><td>10:19</td><td>0101010101</td><td colspan="2">Synchronization sequence</td></tr>
<tr><td>20</td><td>0</td><td colspan="2">Start bit</td></tr>
<tr><td>21</td><td>1</td><td colspan="2">Indication for digital modem</td></tr>
<tr><td>22</td><td>1</td><td colspan="2">Indication for QCA</td></tr>
<tr><td>23</td><td>P</td><td colspan="2">Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)</td></tr>
<tr><td rowspan="5">24:29</td><td rowspan="5">000LM1</td><td>LM</td><td>Level of ANSpcm</td></tr>
<tr><td>00</td><td>−9.5 dBm0</td></tr>
<tr><td>01</td><td>−12 dBm0</td></tr>
<tr><td>10</td><td>−15 dBm0</td></tr>
<tr><td>11</td><td>−18 dBm0</td></tr>
<tr><td>30:39</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
<tr><td>40:49</td><td>0101010101</td><td colspan="2">Bits 10:19 repeated</td></tr>
<tr><td>50:59</td><td>011P000LM1</td><td colspan="2">Bits 20:29 repeated</td></tr>
<tr><td>60:69</td><td>1111111111</td><td colspan="2">Ten ONEs</td></tr>
</table>

8.3.5 QCA2d

Signal QCA2d is a sequence of bits transmitted using V.21(L) modulation. The bits are transmitted using the signal structure defined in clause 7/V.8 *bis* and the information field structure defined in clause 8/V.8 *bis*. The analogue modem shall encode the identification field as defined in Table 14.

Table 14/V.92 – Definition of identification field in QCA2d

Bit position	Content	Definition
0:3	1011	Message type
4:7	VVVV	V.8 *bis* revision number (Note)
8:9	LM	Level of ANSpcm from Table 11
10:12	000	Reserved for the ITU
13	P	Set to 1 calls for LAPM protocol according to ITU-T V.42 (see 9.2.5)
14	1	QCA identifier
15	1	Digital modem
NOTE – At the time of publication the V.8 *bis* revision number is 0100. The receiving modem shall ignore this field.		

8.3.6 QTS

Signal QTS consists of 128 repetitions of the sequence {+V, +0, +V, −V, −0, −V} where V is defined to be the PCM codeword whose Ucode is U_{QTS} and 0 is the PCM codeword with Ucode 0. QTS\ consists of 8 repetitions of the sequence {−V, −0, −V, +V, +0, +V}.

The first symbol of QTS is defined to be transmitted in data frame interval 0. The digital modem shall keep data frame alignment from this point on.

8.4 Full and short Phase 2 signals and sequences

All full and short Phase 2 signals and sequences are defined in ITU-T V.90.

8.4.1 INFO information bits

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 15 defines the bits in the $INFO_{0d}$ sequence. Bit 0 is transmitted first in time.

Table 15/V.92 – Definition of bits in $INFO_{0d}$

$INFO_{0d}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12	Set to 1 indicates symbol rate 2743 is supported in V.34 mode
13	Set to 1 indicates symbol rate 2800 is supported in V.34 mode
14	Set to 1 indicates symbol rate 3429 is supported in V.34 mode
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting in V.34 mode
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions in V.34 mode. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps
24	Set to 1 in an $INFO_{0d}$ sequence transmitted from a CME modem
25	Set to 1 indicates the ability to support up to 1664-point signal constellations
26	Set to 1 requests short Phase 2 to be used
27	V.92 capability: 1
28	Set to 1 to acknowledge correct reception of an $INFO_{0a}$ frame during error recovery

Table 15/V.92 – Definition of bits in $INFO_{0d}$ *(concluded)*

$INFO_{0d}$ bits LSB:MSB	Definition
29:32	Digital modem nominal transmit power for Phase 2. This is represented in −1 dBm0 steps where 0 represents −6 dBm0 and 15 represents −21 dBm0
33:37	Maximum digital modem transmit power. This is represented in −0.5 dBm0 steps where 0 represents −0.5 dBm0 and 31 represents −16 dBm0
38	Set to 1 indicates the digital modem's power shall be measured at the output of the codec. Otherwise the digital modem's power shall be measured at its terminals
39	PCM coding in use by the digital modem: 0 = μ-law, 1 = A-law
40	Set to 1 indicates ability to operate V.90 with an upstream symbol rate of 3429
41	Reserved for the ITU: This bit is set to 0 by the digital modem and not interpreted by the analogue modem
42:57	CRC
58:61	Fill bits: 1111
NOTE 1 – Bits 12, 13, 14 and 40 are used to indicate the modem's capabilities and/or configuration. The values of bits 15 to 20 depend upon regulatory requirements and apply only to the modem's transmitter. NOTE 2 – Bit 24 may be used in conjunction with the PSTN access category octet defined in ITU-T V.8 to determine the optimum parameters for the signal converters and error-control functions in the analogue and digital modem and any intervening CME.	

Table 16 defines the bits in the $INFO_{0a}$ sequence. Bit 0 is transmitted first in time.

Table 16/V.92 – Definition of bits in $INFO_{0a}$

$INFO_{0a}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12	Set to 1 indicates symbol rate 2743 is supported in V.34 mode
13	Set to 1 indicates symbol rate 2800 is supported in V.34 mode
14	Set to 1 indicates symbol rate 3429 is supported in V.34 mode
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting in V.34 mode or in V.90 mode

Table 16/V.92 – Definition of bits in $INFO_{0a}$ *(concluded)*

$INFO_{0a}$ bits LSB:MSB	Definition
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions in V.34 mode. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps
24	Set to 1 in an $INFO_{0a}$ sequence transmitted from a CME modem
25	Set to 1 indicates the ability to support up to 1664-point signal constellations
26	V.92 capability: 1
27	Set to 1 requests short Phase 2 to be used
28	Set to 1 to acknowledge correct reception of an $INFO_{0d}$ frame during error recovery
29:44	CRC
45:48	Fill bits: 1111
NOTE 1 – Bits 12 to 14 are used to indicate the modem's capabilities and/or configuration. The values of bits 15 to 20 depend upon regulatory requirements and apply only to the modem's transmitter. NOTE 2 – Bit 24 may be used in conjunction with the PSTN access category octet defined in ITU-T V.8 to determine the optimum parameters for the signal converters and error-control functions in the analogue and digital modem and any intervening CME.	

Table 17 defines the bits in the $INFO_{1d}$ sequence. Bit 0 is transmitted first in time.

Table 17/V.92 – Definition of bits in $INFO_{1d}$

$INFO_{1d}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:14	Minimum power reduction to be implemented by the analogue modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if $INFO_{0a}$ indicated that the analogue modem transmitter cannot reduce its power
15:17	Additional power reduction, below that indicated by bits 12:14, which can be tolerated by the digital modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if $INFO_{0a}$ indicated that the analogue modem transmitter cannot reduce its power
18:24	Length of MD to be transmitted by the digital modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35-ms increments
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the analogue modem to the digital modem for a symbol rate of 2400

Table 17/V.92 – Definition of bits in $INFO_{1d}$ *(concluded)*

$INFO_{1d}$ bits LSB:MSB	Definition
26:29	Pre-emphasis filter to be used in transmitting from the analogue modem to the digital modem for a symbol rate of 2400. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3/V.34 and 4/V.34)
30:33	Projected maximum data rate for a symbol rate of 2400. These bits form an integer between 0 and 14 which gives the projected data rate as a multiple of 2400 bits/s. A 0 indicates the symbol rate cannot be used
34:42	Probing results pertaining to a final symbol rate selection of 2743 symbols per second. The coding of these 9 bits is identical to that for bits 25-33
43:51	Probing results pertaining to a final symbol rate selection of 2800 symbols per second. The coding of these 9 bits is identical to that for bits 25-33
52:60	Probing results pertaining to a final symbol rate selection of 3000 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in $INFO_{0a}$
61:69	Probing results pertaining to a final symbol rate selection of 3200 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in $INFO_{0a}$
70	Set to 0 indicates that the channel does not support PCM upstream
71:78	Probing results pertaining to a final symbol rate selection of 3429 symbols per second. The coding of these 8 bits is identical to that for bits 26-33. Information in this field shall be consistent with the analogue modem capabilities indicated in $INFO_{0a}$
79:88	Frequency offset of the probing tones as measured by the digital modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 88 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to –512 indicating that this field is to be ignored
89:104	CRC
105:108	Fill bits: 1111
NOTE 1 – Projected maximum data rates greater than 12 in bits 30:33 shall only be indicated when the analogue modem supports up to 1664-point signal constellations. NOTE 2 – The analogue modem may be able to achieve a higher downstream data signalling rate in V.90 mode if the digital modem indicates that the analogue modem may transmit at a lower power in bits 15:17.	

Table 18 defines the bits in the $INFO_{1a}$ sequence that an analogue modem uses to indicate that PCM upstream operation is desired. The analogue modem shall not use this sequence if bit 70 of $INFO_{1d}$ is clear. Bit 0 is transmitted first in time.

Table 18/V.92 – Definition of bits in $INFO_{1a}$ if PCM upstream is selected

$INFO_{1a}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:13	Number of filter sections in precoder and prefilter 0 = $p_1(i)$ and $z_2(i)$ are supported 1 = $z_1(i)$, $p_1(i)$ and $z_2(i)$ are supported 2 = $p_1(i)$, $p_2(i)$ and $z_2(i)$ are supported 3 = $z_1(i)$, $p_1(i)$, $p_2(i)$ and $z_2(i)$ are supported
14:15	Integer number indicating the maximum number of coefficients supported by analogue modem in multiples of 64 starting at 192 $L_{tot} = LZ_1 + LP_1 + LZ_2 + LP_2$ 0 = 192; 1 = 256; 2 = 320; 3 = 384
16:17	Integer number indicating the maximum number of coefficients supported by analogue modem for each filter section in multiples of 64 starting at 128 $L_{max} = \max \{LZ_1, LP_1, LZ_2, LP_2\}$ 0 = 128; 1 = 192; 2 = 256; 3 = 320
18:24	Length of MD to be transmitted by the analogue modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 276 symbol (34.5 ms) increments
25:31	U_{INFO}: Ucode of the PCM codeword to be used by the digital modem for the 2-point train. The power of this point shall not exceed the maximum digital modem transmit power. U_{INFO} shall be greater than 66
32:33	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
34:36	Symbol rate of 8000 to be used by the analogue modem: The integer 6
37:39	Symbol rate of 8000 to be used by the digital modem: The integer 6
40:49	Reserved for the ITU: These bits are set to 1 by the analogue modem and are not interpreted by the digital modem (Note)
50:65	CRC
66:69	Fill bits: 1111
NOTE – These bits are set to 1 to avoid generating a tone.	

Table 19 defines the bits in the $INFO_{1a}$ sequence that an analogue modem uses during short Phase 2 to indicate that V.34 upstream operation is desired. Bit 0 is transmitted first in time.

Table 19/V.92 – Definition of bits in $INFO_{1a}$ if V.34 upstream is selected during short Phase 2

$INFO_{1a}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:17	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
18:24	Length of MD to be transmitted by the analogue modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35-ms increments
25:31	U_{INFO}: Ucode of the PCM codeword to be used by the digital modem for the 2-point train. The power of this point shall not exceed the maximum digital modem transmit power. U_{INFO} shall be greater than 66
32	Reserved for the ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
33	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the analogue modem to the digital modem
34:36	Symbol rate to be used in transmitting from the analogue modem to the digital modem. An integer between 3 and 5 gives the symbol rate, where 3 represents 3000 and 5 represents 3429
37:39	Symbol rate of 8000 to be used by the digital modem: The integer 6
40:49	Frequency offset of the probing tones as measured by the analogue modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02-Hz increments. Bit 49 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to –512 indicating that this field is to be ignored
50:65	CRC
66:69	Fill bits: 1111

8.5 Phase 3 signals for the analogue modem

8.5.1 CP_t

CP_t contains modulation parameters for use by the digital modem during training. CP_t is transmitted using the same modulation as TRN_{1u}. CP_t is scrambled and differentially encoded by modulo 2 addition of the present bit with the previously transmitted bit. The differential encoder memory shall be initialized with the final symbol of the preceding TRN_{1u} and 24 differentially encoded binary ones shall be transmitted prior to transmitting the first CP_t in a series of CP_t sequences. Bit fields for CP_t sequences are defined in Table 23. Bit 0 is transmitted first.

CP_t sequences are defined to be of variable length. A constellation mask consists of 128 bits where a bit set to 1 indicates that the constellation includes the PCM code represented by the corresponding Ucode. Constellations that are identical in two or more data frame intervals only need to be included once in a CP sequence. The constellations that are sent are indexed from 0 (in bits 136:271) to a maximum of 5 (in bits 816:951). If the constellations at the digital modem's transmitter differ from

those at the output to the codec's D/A converter, then bit 128 shall be set and the constellation at the output to the codec's D/A converter corresponding to each transmit constellation shall be sent. Due to the variability in the number of constellations, a parameter γ is defined to be 136 × (the maximum constellation index given in bits 103:127) and a parameter δ is defined to be $(2 \times \gamma) + 136$ if bit 128 is set and γ if bit 128 is clear.

The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple CP_t sequences are transmitted as a group, they shall all contain identical information.

8.5.2 E_{1u}

E_{1u} is a data frame of scrambled, differentially encoded zeroes used to signal the end of CP_t. It is transmitted using the same modulation as CP_t.

8.5.3 MD

As defined in 10.1.3.5/V.34.

8.5.4 J_a

Sequence J_a consists of 24 binary ones followed by repetitions of the DIL descriptor detailed in Table 20. When N = 0, the DIL descriptor is 276 bits long. The modulation used for transmitting J_a is as defined for TRN_{1u}. J_a is scrambled and differentially encoded by modulo 2 addition of the present bit with the previously transmitted bit. The differential encoder memory shall be initialized with the final symbol of the preceding TRN_{1u} at the start of J_a. Transmission of sequence J_a may be terminated without completing the final DIL descriptor. J_a shall be an integer multiple of 12 bits long.

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 20/V.92 – Definition of bits in the DIL descriptor

LSB:MSB	Definition
$0{:}187 + \beta + \lceil N/2 \rceil \times 17$	As defined in 8.3.1/V.90
$188 + \beta + \lceil N/2 \rceil \times 17$: $203 + \beta + \lceil N/2 \rceil \times 17$	Data signalling rate capability mask Bit $188 + \beta + \lceil N/2 \rceil \times 17$: 24 000; bit $189 + \beta + \lceil N/2 \rceil \times 17$: 25 333; …; bit $203 + \beta + \lceil N/2 \rceil \times 17$: 44 000. Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the analogue modem
$204 + \beta + \lceil N/2 \rceil \times 17$	Start bit: 0
$205 + \beta + \lceil N/2 \rceil \times 17$: $220 + \beta + \lceil N/2 \rceil \times 17$	Data signalling rate capability mask (continued) Bit $205 + \beta + \lceil N/2 \rceil \times 17$: 45 333; bit $206 + \beta + \lceil N/2 \rceil \times 17$: 46 666; bit $207 + \beta + \lceil N/2 \rceil \times 17$; 48 000; bits $208 + \beta + \lceil N/2 \rceil \times 17$ to $220 + \beta + \lceil N/2 \rceil \times 17$: Reserved for the ITU. (These bits are set to 0 by the analogue modem and are not interpreted by the digital modem.) Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the analogue modem
$221 + \beta + \lceil N/2 \rceil \times 17$	Start bit: 0
$222 + \beta + \lceil N/2 \rceil \times 17$: $237 + \beta + \lceil N/2 \rceil \times 17$	CRC
$238 + \beta + \lceil N/2 \rceil \times 17$	Fill bit: 0
$239 + \beta + \lceil N/2 \rceil \times 17\ldots$	Fill bits: 0s to extend the J_a sequence length to the next multiple of 12 bits

8.5.5 R_u

Signal R_u is transmitted by repeating the 6-symbol sequence $\{+L_U, +L_U, +L_U, -L_U, -L_U, -L_U\}$. Signal $\overline{R_u}$ is transmitted by repeating the 6-symbol sequence $\{-L_U, -L_U, -L_U, +L_U, +L_U, +L_U\}$.

The analogue modem shall bypass the precoder and prefilter structure whenever transmitting signal R_u and $\overline{R_u}$. It shall use the same structure used while transmitting 2 point TRN_{1u} signal.

8.5.6 S_u

Signal S_u is transmitted by repeating the 6-symbol sequence $\{+\sqrt{(3/2)} \times L_U, 0, +\sqrt{(3/2)} \times L_U, -\sqrt{(3/2)} \times L_U, 0, -\sqrt{(3/2)} \times L_U\}$. Signal $\overline{S_u}$ is transmitted by repeating the 6-symbol sequence $\{-\sqrt{(3/2)} \times L_U, 0, -\sqrt{(3/2)} \times L_U, +\sqrt{(3/2)} \times L_U, 0, +\sqrt{(3/2)} \times L_U\}$. Signals S_u and $\overline{S_u}$ shall be an integer multiple of 12 symbols in length.

8.5.7 TRN_{1u}

Signal TRN_{1u} is a sequence of $\pm L_U$ values. The signs of TRN_{1u} are generated by applying binary ones to the input of the scrambler described in 6.3. A scrambler output of 0 represents a positive voltage; a scrambler output of 1 represents a negative voltage.

The scrambler shall be initialized to zero prior to the transmission of TRN_{1u}.

TRN_{1u} segments shall be an integer multiple of 12 symbols in length. The digital modem shall keep data frame interval alignment from the first symbol of the second TRN_{1u} signal.

8.6 Phase 3, signals for the digital modem

The digital modem shall use the polynomial, GPC, in equation 7-1/V.34 when generating signals J_d, J_p, J_p', SCR and TRN_{1d}. Signals transmitted by the digital modem during Phase 3 are not spectrally shaped.

8.6.1 DIL

As defined in 8.4.1/V.90.

8.6.2 J_d

Sequence J_d consists of a whole number of repetitions of the bit pattern given in Table 21. Bit 0 is transmitted first. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO}. A sign of 0 represents a negative voltage; a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted TRN_{1d}.

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 21/V.92 – Definition of bits in J_d

J_d bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18:33	Data signalling rate capability mask. Bit 18:28 000; bit 19:29 333; bit 20:30 666; …; bit 33:48 000. Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the digital modem
34	Start bit: 0
35:40	Data signalling rate capability mask (continued). Bit 35:49 333; bit 36:50 666; …; bit 39:54 666; bit 40:56 000. Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the digital modem
41:46	Reserved for the ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
47	J_d/J_p identifier: 0 = J_d, 1 = J_p
48	Reserved for the ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
49:50	A number between 1 and 3 indicating the digital modem's maximum look-ahead for spectral shaping
51	Start bit: 0
52:67	CRC
68:71	Fill bits: 0000

8.6.3 J_p

Sequence J_p consists of a whole number of repetitions of the bit pattern given in Table 22. Bit 0 is transmitted first. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO}. A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted J_d.

The digital modem is not capable of changing the sampling phase of the central office A/D. Hence, it shall use signal J_p to indicate its desire to the analogue modem to adjust its transmitter phase from [0, 1) symbol or [0, T) seconds.

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 22/V.92 – Definition of bits in J_p

J_p bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18:33	Fractional amount that signal $\overline{S_u}$ corresponding to signal J_p to J_p' transition needs to be extended. 16-bit unsigned integer covering the range [0, 1) symbol or [0, T) seconds
34	Start bit: 0
35:46	Reserved for the ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
47	J_d/J_p identifier: 0 = J_d, 1 = J_p
48	Size of constellation used to transmit CP_u, E_{2u}, SUV_u and TRN_{2u} during training sequences: 0 = 4-point constellation; 1 = 8-point constellation
49	Size of constellation used to transmit CP_u, E_{2u}, SUV_u and TRN_{2u} during rate renegotiation procedures: 0 = 4-point constellation; 1 = 8-point constellation
50	Reserved for the ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
51	Start bit: 0
52:67	CRC
68:71	Fill bits: 0000

8.6.4 J_p'

J_p' is used to terminate J_p. J_p' consists of 12 binary zeroes. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO}. A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted J_p.

8.6.5 R_i

As defined in 8.6.4/V.90.

8.6.6 SCR

SCR is a sequence of the PCM codeword whose Ucode is U_{INFO} with signs generated by applying binary ones to the input of the scrambler. The scrambler does not need to be initialized at the beginning of SCR. A sign of 0 represents a negative voltage; a sign of 1 represents a positive voltage. SCR shall be an integer multiple of 6 symbols long.

8.6.7 S_d

As defined in 8.4.4/V.90.

8.6.8 TRN_{1d}

As defined in 8.4.5/V.90.

8.7 Phase 4, Rate Renegotiation and Fast Parameter Exchange signals for the analogue modem

8.7.1 $B1_u$

$B1_u$ is 48 data frames of scrambled binary ones transmitted using the data mode constellation parameters from the preceding CP_d. The first transmitter output symbol in the first data frame corresponds to n = 0 in the prefilter and precoder filter output equations in 6.4.2. A data frame in the upstream direction is 12 symbols long. The first symbol of $B1_u$ shall begin data frame interval 0. The scrambler, modulus encoder, convolutional encoder, precoder and prefilter memories are initialized to zero prior to transmitting $B1_u$.

8.7.2 E_{2u}

E_{2u} is a data frame of scrambled, differentially encoded zeroes. It is transmitted using the corresponding TRN_{2u} modulation during Training and Rate Renegotiation. During Fast Parameter Exchange it is transmitted using the preceding data mode modulation. E_{2u} shall be extended by a single symbol if bit 29 of CP_d is set.

8.7.3 CP_u

There are 2 types of CP_u sequences: a long one and a short one.

The long CP_u sequence contains modulation parameters for use by the digital modem in data mode. The long CP_u sequence is transmitted using the corresponding TRN_{2u} modulation during training and rate renegotiation procedures and it is transmitted using the same modulation parameters as data mode during fast parameter exchange procedures. For training and rate renegotiation, the differential encoder is initialized using the last transmitted sign bit of the preceding sequence. A CP_u with the acknowledge bit set is denoted CP_u'. Bit fields for CP_u sequences are defined in Table 23. Bit 0 is transmitted first.

Table 23/V.92 – Definition of bits in CP_u and CP_t

CP_u and CP_t bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	CP: 0
19:20	Type: CP_t denoted by 0; CP_u denoted by 1
21:25	Selected digital modem to analogue modem data signalling rate, an integer, drn, between 0 and 22. drn = 0 indicates cleardown. Data signalling rate = (drn + 20) × 8000/6 in CP_u and (drn + 8) × 8000/6 in CP_t
26:30	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
31:32	S_r: The number of sign bits used as redundancy for spectral shaping
33	Acknowledge bit: 0 = modem has not received CP_d from the digital modem, 1 = received CP_d from the digital modem
34	Start bit: 0

Table 23/V.92 – Definition of bits in CP_u and CP_t *(continued)*

CP_u and CP_t bits LSB:MSB	Definition
35	Codec type: 0 = μ-law; 1 = A-law
36:48	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
49:50	ld: Number of look-ahead frames requested during spectral shaping. This shall be consistent with the capabilities of the digital modem indicated in J_d
51	Start bit: 0
52:67	The RMS value of TRN_{1d} at the transmitter output divided by the RMS value of TRN_{1d} at the output to the codec's D/A converter expressed in unsigned Q3.13 format (xxx.xxxxxxxxxxxxx)
68	Start bit: 0
69:76	Parameter a_1 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
77:84	Parameter a_2 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
85	Start bit: 0
86:93	Parameter b_1 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
94:101	Parameter b_2 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
102	Start bit: 0
103:106	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 0
107:110	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 1
111:114	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 2
115:118	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 3
119	Start bit: 0
120:123	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 4
124:127	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 5
128	Set to 1 if the constellations at the transmitter differ from those at the output to the codec's D/A converter
129:135	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
136	Start bit: 0
137:152	Constellation mask for $Uchord_1$ (bit 137 corresponds to Ucode 0)
153	Start bit: 0
154:169	Constellation mask for $Uchord_2$ (bit 154 corresponds to Ucode 16)

Table 23/V.92 – Definition of bits in CP_u and CP_t *(concluded)*

CP_u and CP_t bits LSB:MSB	Definition
170	Start bit: 0
171:186	Constellation mask for $Uchord_3$ (bit 171 corresponds to Ucode 32)
187	Start bit: 0
188:203	Constellation mask for $Uchord_4$ (bit 188 corresponds to Ucode 48)
204	Start bit: 0
205:220	Constellation mask for $Uchord_5$ (bit 205 corresponds to Ucode 64)
221	Start bit: 0
222:237	Constellation mask for $Uchord_6$ (bit 222 corresponds to Ucode 80)
238	Start bit: 0
239:254	Constellation mask for $Uchord_7$ (bit 239 corresponds to Ucode 96)
255	Start bit: 0
256:271	Constellation mask for $Uchord_8$ (bit 256 corresponds to Ucode 112)
$272{:}271 + \gamma$	Possibly more constellations in same format as bits 136:271
$272 + \gamma{:}271 + \delta$	Corresponding codec constellations in same format as bits 136:271
$272 + \delta$	Start bit: 0
$273 + \delta{:}288 + \delta$	CRC
$289 + \delta$	Fill bit: 0
$289 + \delta{:}\ldots$	Fill bits: 0s to extend the CP sequence length to the next multiple of 12 symbols

The long CP_u sequences are defined to be of variable length. A constellation mask consists of 128 bits where a bit set to 1 indicates that the constellation includes the PCM code represented by the corresponding Ucode. Constellations that are identical in two or more data frame intervals only need to be included once in a CP sequence. The constellations that are sent are indexed from 0 (in bits 136:271) to a maximum of 5 (in bits 816:951). If the constellations at the digital modem's transmitter differ from those at the output to the codec's D/A converter, then bit 128 shall be set and the constellation at the output to the codec's D/A converter corresponding to each transmit constellation shall be sent. Due to the variability in the number of constellations, a parameter γ is defined to be 136×(the maximum constellation index given in bits 103:127) and a parameter δ is defined to be $(2 \times \gamma) + 136$ if bit 128 is set and γ if bit 128 is clear.

CP_{us} denotes a short CP_u sequence used in rate renegotiation and fast parameter exchange procedures when the digital modem's modulation parameters are not changed. CP_{us} is transmitted using the same modulation parameters as TRN_{2u} during rate renegotiation procedures and it is transmitted using the same modulation as data mode during fast parameter exchange procedures. For rate renegotiation, the differential encoder is initialized using the last transmitted sign bit of the preceding sequence. Bit fields for CP_{us} sequences are defined in Table 24. Bit 0 is transmitted first.

The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple CP_u and CP_u' sequences are transmitted as a group, they shall all contain identical information.

Table 24/V.92 – Definition of bits in CP_{us}

CP_{us} bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	CP: 0
19:20	CP_{us}: 2
21:25	Selected digital modem to analogue modem data signalling rate, an integer, drn, between 0 and 22. drn = 0 indicates cleardown. Data signalling rate = (drn + 20)*8000/6
26:32	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
33	Acknowledge bit: 0 = modem has not received CP_d from the digital modem, 1 = received CP_d from the digital modem
34	Start bit: 0
35:50	CRC
51	Fill bit: 0
52:…	Fill bits: 0s to extend the CP_{us} sequence length to the next multiple of 12 symbols

8.7.4 R_M

R_M is transmitted by repeating the 12-symbol pattern as defined in Table 25.

Table 25/V.92 – Symbol pattern for signal R_M

Data Frame Interval, i	Modulus Encoder output K_i
0	$K_0 = M_0 – 1$
1	$K_1 = M_1 – 1$
2	$K_2 = 0$
3	$K_3 = 0$
4	$K_4 = M_4 – 1$
5	$K_5 = M_5 – 1$
6	$K_6 = 0$
7	$K_7 = 0$
8	$K_8 = M_8 – 1$
9	$K_9 = M_9 – 1$
10	$K_{10} = 0$
11	$u_{11} = 0$

R_M' is transmitted by repeating the 12-symbol pattern as defined in Table 26.

Table 26/V.92 – Symbol pattern for signal R_M'

Data Frame Interval, i	Modulus Encoder output K_i
0	$K_0 = 0$
1	$K_1 = 0$
2	$K_2 = M_2 - 1$
3	$K_3 = M_3 - 1$
4	$K_4 = 0$
5	$K_5 = 0$
6	$K_6 = M_6 - 1$
7	$K_7 = M_7 - 1$
8	$K_8 = 0$
9	$K_9 = 0$
10	$K_{10} = M_{10} - 1$
11	$k_{11} = M_{11} - 1$

Sequences R_M and R_M' are transmitted using the constellation parameters used for the data mode. The analogue modem shall use the same precoder and prefilter structure used in the latest data mode. Sequences R_M and R_M' shall be trellis encoded.

8.7.5 SUV_u

SUV_u is a short information sequence. SUV_u is scrambled and transmitted using the corresponding TRN_{2u} modulation during Training and Rate Renegotiation. During Fast Parameter Exchange it is transmitted using preceding data mode modulation. The differential encoder is initialized using the last transmitted sign bit of the preceding sequence. An SUV_u with the acknowledge bit set is denoted SUV_u'. Bit fields for SUV_u sequences are defined in Table 27. Bit 0 is transmitted first.

The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple SUV_u and SUV_u' sequences are transmitted as a group, they shall all contain identical information.

Table 27/V.92 – Definition of bits in SUV_u

SUV_u bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	SUVu: 1
19:25	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
26	Set to 1 indicates that the analogue modem wishes the digital modem to wait for a CP_u before sending a CP_d. The digital modem is not required to comply with this request

Table 27/V.92 – Definition of bits in SUV_u *(concluded)*

SUV_u bits LSB:MSB	Definition
27:31	$20 \times \log10(L)$ where L is the measured RMS level of the prefilter output multiplied by G . This result is expressed in signed Q2.2 format (sxx.xx). The value 16 (−4.00) indicates that no measurement has been taken
32	Set to 1 indicates that a silent period is requested. This may be used during rate renegotiation (see 9.8.2.1)
33	Acknowledge bit: 0 = modem has not received CP_d from the digital modem, 1 = received CP_d from the digital modem
34	Start bit: 0
35:50	CRC
51	Fill bit: 0
52:…	Fill bits: 0s to extend the SUV_u sequence length to the next multiple of 12 symbols

8.7.6 TRN_{2u}

TRN_{2u} is a 4- or 8-point constellation signal as requested by the digital modem via J_p bits 48 and 49.

TRN_{2u} consists of scrambled binary ones. The mapping of the scrambler output to symbols shall be done according to the rules defined in Tables 28 and 29. The scrambler shall be reset at the beginning of TRN_{2u}. The sign bit of TRN_{2u} is differentially encoded by modulo 2 addition of the present sign bit with the previously transmitted sign bit. The differential encoder memory shall be initialized with the last transmitted sign bit of the preceding E_{1u} sequence. TRN_{2u} shall be an integer multiple of 12 symbols in length. TRN_{2u} maybe used to estimate the analogue channel for upstream.

Table 28/V.92 – Mapping of bits to symbols for 4-point TRN_{2u}

MSB:LSB	Linear value
00	$(1/\sqrt{5}) \times L_U$
01	$(3/\sqrt{5}) \times L_U$
10	$-(1/\sqrt{5}) \times L_U$
11	$-(3/\sqrt{5}) \times L_U$

Table 29/V.92 – Mapping of bits to symbols for 8-point TRN_{2u}

MSB:LSB	Linear value
000	$(1/\sqrt{21}) \times LU$
001	$(3/\sqrt{21}) \times LU$
010	$(5/\sqrt{21}) \times LU$
011	$(7/\sqrt{21}) \times LU$
100	$-(1/\sqrt{21}) \times LU$
101	$-(3/\sqrt{21}) \times LU$
110	$-(5/\sqrt{21}) \times LU$
111	$-(7/\sqrt{21}) \times LU$

8.7.7 $FB1_u$

$FB1_u$ is 48 data frames of scrambled, differentially encoded binary ones. It is transmitted using the preceding data mode modulation.

8.8 Phase 4, Rate Renegotiation and Fast Parameter Exchange signals for the digital modem

8.8.1 $B1_d$

As defined in 8.6.1/V.90.

8.8.2 E_d

E_d consists of 2 data frames of scrambled binary zeros. It is transmitted using corresponding TRN_{2d} modulation during Training and Rate Renegotiation. During Fast Parameter Exchange it is transmitted using the preceding data mode modulation.

8.8.3 CP_d

CP_d contains modulation parameters for use by the analogue modem in data mode. There are four parts to a CP_d sequence. The first part, occupying bits 0 to 50, is always sent. The other three parts are optional and their presence is indicated by bits 19 to 21. These parts contain the modulus encoder parameters, the prefilter and precoder coefficients and the constellation sets respectively. All the bits contained in a part are removed from the CP_d sequence when it is indicated that the part is not present. All CP_d sequences end with a CRC field followed by at least one fill bit. CP_d is scrambled and transmitted using the corresponding TRN_{2d} modulation during Training and Rate Renegotiation. During Fast Parameter Exchange it is transmitted using the preceding data mode modulation. For training and rate renegotiation, the differential encoder is initialized using the last transmitted sign bit of the preceding sequence. A CP_d with the acknowledge bit set is denoted CP_d'. Bit fields for CP_d sequences are defined in Table 30. Bit 0 is transmitted first.

The bit positions given in Table 30 assume that all parts of CP_d are present. The precoder and prefilter coefficients and the constellation sets in the CP_d sequences are defined to be of variable length. Due to this variability a parameter α is defined to be $17 \times (LZ_1 + LP_1 + LZ_2 + LP_2)$ and a parameter β is defined to be $17 \times (LC_1 + LC_2 + LC_3 + LC_4 + LC_5 + LC_6)$. The bit positions of the actual CP_d that is transmitted will depend on which parts are present. The modulus encoder parameters, if present, are transmitted using 6 words. The precoder and prefilter coefficients, if present, are transmitted using $4 + LZ_1 + LP_1 + LZ_2 + LP_2$ words, where $LZ_1 + LP_1 + LZ_2 + LP_2$

shall not exceed L_{tot} given in bits 14:15 of $INFO_{1a}$. The constellation sets, if present, are transmitted using 5 + LC_1 + LC_2 + LC_3 + LC_4 + LC_5 + LC_6 words. Constellations shall not contain the zero point. All of the constellation sets with non-zero size shall be listed first. The number of points in a constellation set shall not exceed 128.

The digital modem shall design the modulation parameters assuming that, when the prefilter output multiplied by G has a mean-square value of 1, the analogue modem will transmit at the desired power.

The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple CP_d and CP_d' sequences are transmitted as a group, they shall all contain identical information.

NOTE – The digital modem should design the precoder coefficients under the assumption that the analogue modem minimizes the power at the precoder output on a symbol-by-symbol basis.

Table 30/V.92 – Definition of bits in CP_d

CP_d bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	CP_d: 0
19	Set to 1 indicates modulus encoder parameters are present
20	Set to 1 indicates prefilter and precoder coefficients are present
21	Set to 1 indicates constellation sets are present
22:26	Selected analogue modem to digital modem data signalling rate, an integer, drn, between 0 and 19. drn = 0 shall indicate cleardown. Data signalling rate = (drn + 17) × 8000/6
27:28	Trellis encoder select bits in analogue modem to digital modem direction: 0 = 16 state, 1 = 32 state, 2 = 64 state, 3 = Reserved for the ITU. The digital modem receiver requires the analogue modem transmitter to use the selected trellis encoder
29	Extend the length of the E_{2u} sequence: 0 = don't extend; 1 = extend by 1 symbol. This bit shall be set to zero during rate renegotiation and fast parameter exchange procedures
30:32	Reserved for the ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
33	Acknowledge bit: 0 = modem has not received CP_u from the analogue modem, 1 = received CP_u from the analogue modem
34	Start bit: 0
35:50	4 × G > 0 : Four times the gain used at the output of the prefilter in unsigned Q0.16 format (.xxxxxxxxxxxxxxxx)
	Modulus encoder parameters
51	Start bit: 0
52:59	Modulus encoder parameter M_0
60:67	Modulus encoder parameter M_1

Table 30/V.92 – Definition of bits in CP_d *(continued)*

CP_d bits LSB:MSB	Definition
68	Start bit: 0
69:76	Modulus encoder parameter M_2
77:84	Modulus encoder parameter M_3
85	Start bit: 0
86:93	Modulus encoder parameter M_4
94:101	Modulus encoder parameter M_5
102	Start bit: 0
103:110	Modulus encoder parameter M_6
111:118	Modulus encoder parameter M_7
119	Start bit: 0
120:127	Modulus encoder parameter M_8
128:135	Modulus encoder parameter M_9
136	Start bit: 0
137:144	Modulus encoder parameter M_{10}
145:152	Modulus encoder parameter M_{11}
	Precoder and prefilter coefficients
153	Start bit: 0
154:162	LZ_1: Number of taps for feed-forward section of precoder. Up to L_{max} given in bits 16:17 of $INFO_{1a}$
163:169	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
170	Start bit: 0
171:179	LP_1: Number of taps for feedback section of precoder. Up to L_{max} given in bits 16:17 of $INFO_{1a}$
180:186	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
187	Start bit: 0
188:196	LZ_2: Number of taps for feed-forward section of prefilter. Up to L_{max} given in bits 16:17 of $INFO_{1a}$
197:203	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
204	Start bit: 0
205:213	LP_2: Number of taps for feedback section of prefilter. Up to L_{max} given in bits 16:17 of $INFO_{1a}$
214:220	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
221	Start bit: 0

Table 30/V.92 – Definition of bits in CP_d *(continued)*

CP_d bits LSB:MSB	Definition
222:237	1st precoder feed-forward filter coefficient in signed Q0.15 (s.xxxxxxxxxxxxxxx), $z_1(1)$ (if $LZ_1 > 0$)
...	Remaining precoder feed-forward filter coefficients, $z_1(2) : z_1(LZ_1)$
$221 + 17 \times LZ1$	Start bit: 0
$222 + 17 \times LZ1$: $237 + 17 \times LZ1$	1st precoder feedback filter coefficient in signed Q1.14 (sx.xxxxxxxxxxxxxx), $p_1(1)$
...	Remaining precoder feedback filter coefficients, $p_1(2) : p_1(LP_1)$
$221 + 17 \times (LZ1 + LP1)$	Start bit: 0
...	Prefilter feed-forward filter coefficients in signed Q0.15 (s.xxxxxxxxxxxxxxx), $z_2(0) : z_2(LZ_2 - 1)$
$221 + 17 \times (LZ1 + LP1 + LZ2)$	Start bit: 0
…	Prefilter feedback filter coefficients in signed Q1.14 (sx.xxxxxxxxxxxxxx), $p_2(1) : p_2(LP_2)$ (if $LP_2 > 0$)
	Constellation sets
$221 + \alpha$	Start bit: 0
$222 + \alpha$: $225 + \alpha$	An integer between 0 and 5 denoting the index of the constellation to be used in data frame intervals 0 and 6
$226 + \alpha$: $229 + \alpha$	An integer between 0 and 5 denoting the index of the constellation to be used in data frame intervals 1 and 7
$230 + \alpha$: $233 + \alpha$	An integer between 0 and 5 denoting the index of the constellation to be used in data frame intervals 2 and 8
$234 + \alpha$: $237 + \alpha$	An integer between 0 and 5 denoting the index of the constellation to be used in data frame intervals 3 and 9
$238 + \alpha$	Start bit: 0
$239 + \alpha$: $242 + \alpha$	An integer between 0 and 5 denoting the index of the constellation to be used in data frame intervals 4 and 10
$243 + \alpha$: $246 + \alpha$	An integer between 0 and 5 denoting the index of the constellation to be used in data frame intervals 5 and 11
$247 + \alpha$: $254 + \alpha$	Reserved for the ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
$255 + \alpha$	Start bit: 0
$256 + \alpha$: $263 + \alpha$	Number of positive points in the 1st constellation set, LC_1.
$264 + \alpha$: $271 + \alpha$	Number of positive points in the 2nd constellation set, LC_2 (possibly zero)
$272 + \alpha$	Start bit: 0
$273 + \alpha$: $280 + \alpha$	Number of positive points in the 3rd constellation set, LC_3 (possibly zero)
$281 + \alpha$: $288 + \alpha$	Number of positive points in the 4th constellation set, LC_4 (possibly zero)

Table 30/V.92 – Definition of bits in CP_d *(concluded)*

CP_d bits LSB:MSB	Definition
$289 + \alpha$	Start bit: 0
$290 + \alpha: 297 + \alpha$	Number of positive points in the 5th constellation set, LC_5 (possibly zero)
$298 + \alpha: 305 + \alpha$	Number of positive points in the 6th constellation set, LC_6 (possibly zero)
$306 + \alpha$	Start bit: 0
$307 + \alpha: 322 + \alpha$	Linear value of 1st (smallest magnitude) constellation point in the 1st constellation set
$323 + \alpha$	Start bit: 0
…	…
	Linear value of last (largest magnitude) constellation point in the 1st constellation set
$306 + \alpha + 17 \times LC1$	Start bit: 0
	Possibly more constellations in same format (for any non-zero size constellation set).
	End of CP_d sequence
$306 + \alpha + \beta$	Start bit: 0
$307 + \alpha + \beta$: $322 + \alpha + \beta$	CRC
$323 + \alpha + \beta$	Fill bit: 0
$324 + \alpha + \beta$: …	Fill bits: 0s to extend the CP_d sequence length to the next multiple of 6 symbols

8.8.4 R

R_d and R_t are defined in 8.6.4/V.90.

R_f is transmitted by 0 repeating the 12-symbol sequence containing the PCM codewords with the sign pattern + + − − + + − − + + − − where the left-most sign is transmitted first. $\overline{R_f}$ consists of 2 repetitions of the 12-symbol sequence containing the same PCM codewords with the sign pattern − − + + − − + + − − + + where the left-most sign is transmitted first. The PCM codewords used are the highest power PCM codeword from the data mode constellation of each data frame interval as passed in CP_u.

8.8.5 SUV_d

SUV_d is a short information sequence. SUV_d is scrambled and transmitted using the corresponding TRN_{2d} modulation during Training and Rate Renegotiation. During Fast Parameter Exchange it is transmitted using the preceding data mode modulation. The differential encoder is initialized using the last transmitted sign bit of the preceding sequence. An SUV_d with the acknowledge bit set is denoted SUV_d'. Bit fields for SUV_d sequences are defined in Table 31. Bit 0 is transmitted first.

The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple SUV_d and SUV_d' sequences are transmitted as a group, they shall all contain identical information.

Table 31/V.92 – Definition of bits in SUV_d

SUV_d bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	SUV_d: 1
19:31	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
32	Set to 1 indicates that a silent period is requested. This may be used during rate renegotiation (see 9.8.1.1)
33	Acknowledge bit: 0 = modem has not received CP_u from the analogue modem, 1 = received CP_u from the analogue modem
34	Start bit: 0
35:50	CRC
51	Fill bit: 0
52:…	Fill bits: 0s to extend the SUV_d sequence length to the next multiple of 6 symbols

8.8.6 TRN_{2d}

As defined in 8.6.5/V.90.

8.9 Modem-on-hold

8.9.1 RT

Tone RT is either Tone A or Tone B as defined in 8.2/V.90. If the modem transmits Tone A during retrain procedures the modem shall transmit RT as Tone A and detect Tone B during modem-on-hold procedures. If the modem transmits Tone B during retrain procedures the modem shall transmit RT as Tone B and detect Tone A during modem-on-hold procedures.

8.9.2 MH sequences

MH sequences are used to exchange information during modem-on-hold procedures. They use the same modulation as Phase 2 INFO sequences as defined in 8.2.3.1/V.90. The CRC generator used is described in 10.1.2.3.2/V.34.

Table 32 defines the bits in the MH sequences. Bit 0 is transmitted first in time.

Table 32/V.92 – Definition of bits in MH sequences

MH bits LSB:MSB	
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:15	Signal indication bits: 0011 MHreq Request remote modem to go on-hold 0101 MHack Indicate agreement to go on hold and timeout 0111 MHnack Deny on-hold, request cleardown or fast reconnect 1001 MHclrd Request cleardown 1011 MHcda Acknowledge cleardown 1101 MHfrr Request fast reconnect
16:19	Information bits: For signals MHreq, MHnack, MHcda and MHfrr repeat signal indication bits For MHack: 16:19 T1 – Timeout period for on-hold For MHclrd: 16:19 0101 Cleardown due to incoming call 0110 Cleardown due to outgoing call 1010 Cleardown due to other reason
20:35	CRC
36:39	Fill bits: 1111
NOTE 1 – Bit combinations not defined in bits 12-15 are reserved for the ITU. MH sequences with undefined bit combinations should be ignored. NOTE 2 – Bit combinations not defined in bits 16-19 for MHclrd are reserved for the ITU and should not be interpreted by the receiving modem.	

The encoding of timeout period T1 is defined in Table 33.

Table 33/V.92 – Encoding of timeout period T1

Bits 16:19	T1
0000	Reserved for the ITU
0001	10 s
0010	20 s
0011	30 s
0100	40 s
0101	1 min
0110	2 min
0111	3 min
1000	4 min
1001	6 min
1010	8 min

Table 33/V.92 – Encoding of timeout period T1 *(concluded)*

Bits 16:19	T1
1011	12 min
1100	16 min
1101	no limit
1110	Reserved for the ITU
1111	Reserved for the ITU

9 Operating procedures

The start-up procedure carried out after establishing a dialled connection between the two modems consists of four distinct phases:

– Phase 1, network interaction;

– Phase 2, channel probing and ranging;

– Phase 3, equalizer and echo canceller training and digital impairment learning;

– Phase 4, final training.

Both Phase 1 and Phase 2 have a full and a short procedure.

9.1 Full Phase 1 – Network interaction

The operating procedures for full Phase 1 are identical to those for Phase 1 of ITU-T V.90.

NOTE – There is no means in V.8 to exclusively indicate that a modem can do V.92 so that decision must wait.

9.2 Short Phase 1 – Network interaction

The operating procedures for short Phase 1 are given below and are illustrated in Figures 3 to 8.

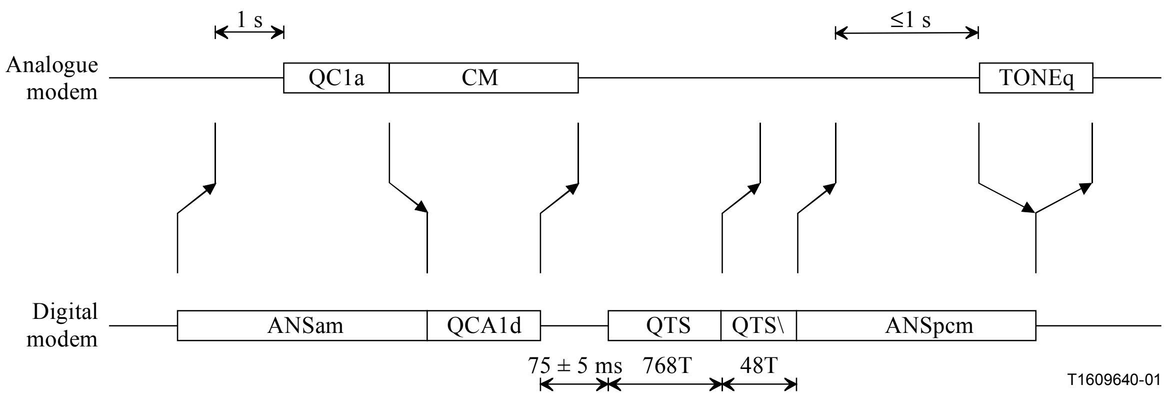


Figure 3/V.92 – Short Phase 1 when calling modem is analogue modem and answering modem transmits ANSam

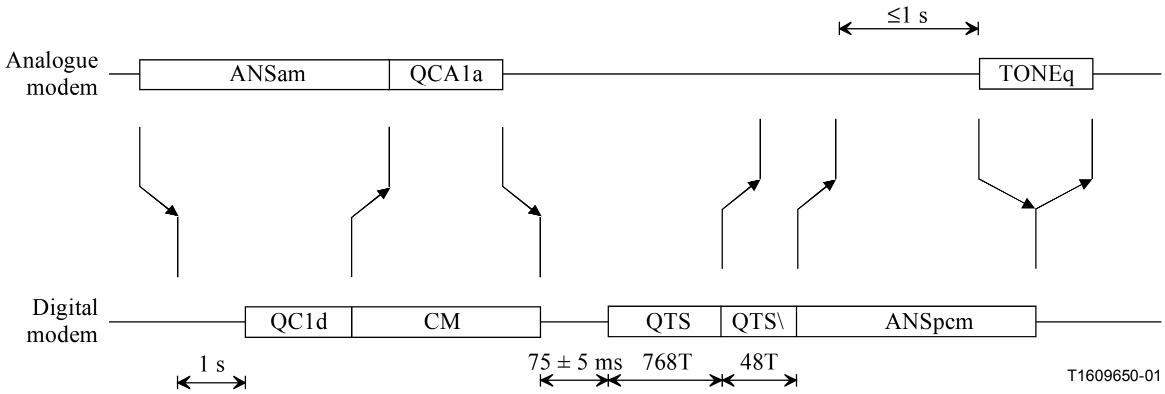


Figure 4/V.92 – Short Phase 1 when calling modem is digital modem and answering modem transmits ANSam

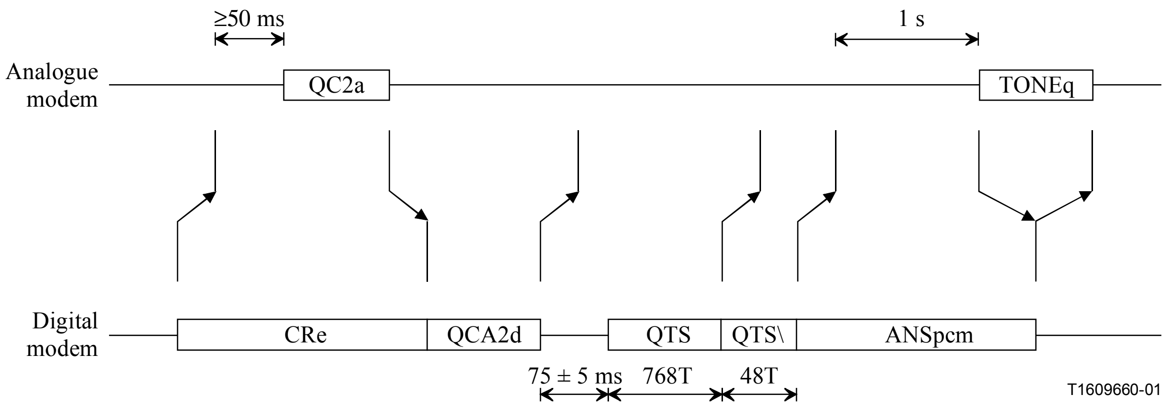


Figure 5/V.92 – Short Phase 1 when calling modem is analogue modem and answering modem transmits CRe

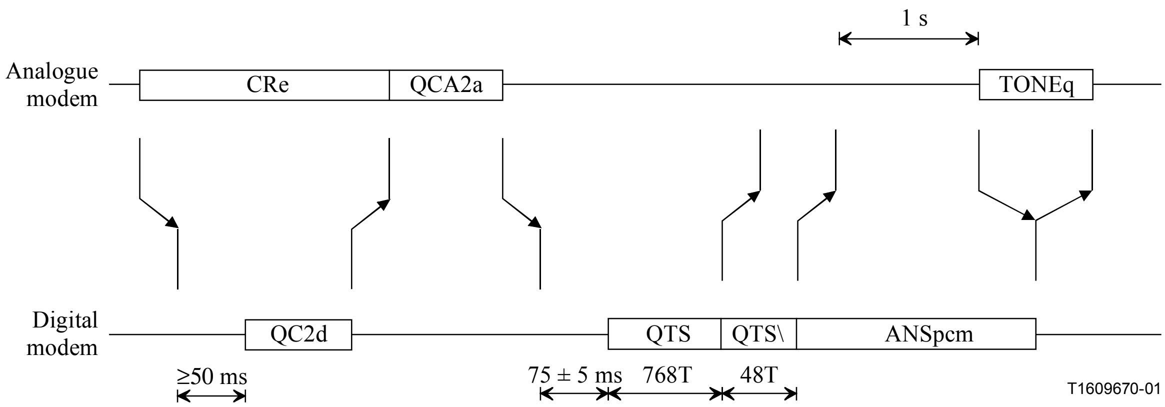


Figure 6/V.92 – Short Phase 1 when calling modem is digital modem and answering modem transmits CRe

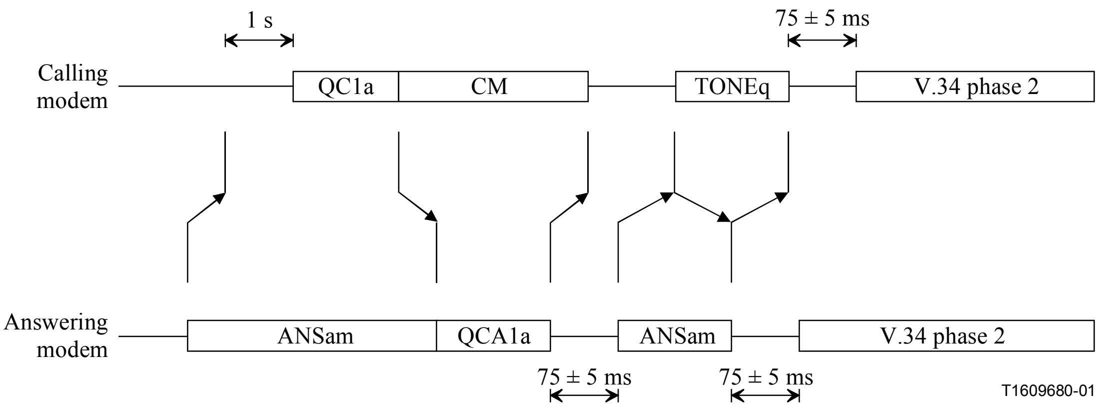


Figure 7/V.92 – Short Phase 1 when both modems are analogue modems and answering modem transmits ANSam

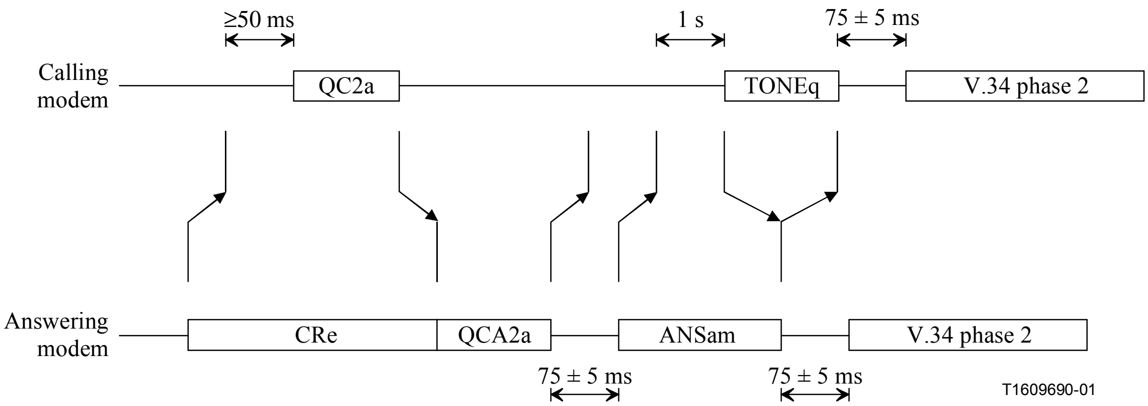


Figure 8/V.92 – Short Phase 1 when both modems are analogue modems and answering modem transmits CRe

9.2.1 Call modem is analogue modem

Initially, the call modem shall condition its receiver to detect signal ANSam as defined in ITU-T V.8 and optionally signal CRe as defined in ITU-T V.8 *bis*.

9.2.1.1 If signal ANSam is detected for 1 s, the analogue modem shall transmit signal QC1a followed by CM and condition its receiver to detect QCA1d, QCA1a and JM. If QCA1d is detected, the modem shall stop transmitting CM without completing the current octet and transmit silence and condition itself to detect QTS and QTS\ followed by ANSpcm and proceed in accordance with 9.2.1.3. If QCA1a is detected, the modem shall stop transmitting CM without completing the current octet and transmit silence until ANSam is detected, then transmit TONEq and proceed according to 9.2.1.4. If JM is detected, the analogue modem shall proceed according to ITU-T V.8.

9.2.1.2 If the initial 50 ms of signal CRe is detected, the analogue modem shall transmit signal QC2a followed by silence and condition its receiver to detect QCA2d, QCA2a, ANSam and ANS. If QCA2d is detected, the modem shall condition itself to detect QTS and QTS\ followed by ANSpcm and proceed according to 9.2.1.3. If QCA2a is detected, the modem shall condition itself to detect ANSam and when ANSam is detected for 1 s, transmit TONEq and proceed in accordance with 9.2.1.4. If ANSam is detected the modem shall proceed according to 9.2.1.1. If ANS is detected for 3 s after sending QC2a, the analogue modem shall proceed according to ITU-T V.8. If neither

QCA2d nor QCA2a is detected 1 s after transmitting QC2a the modem shall proceed in accordance with ITU-T V.8 *bis*.

9.2.1.3 When ANSpcm has been detected for 1 s the modem shall transmit TONEq for a minimum of 50 ms; however, if ANSam was already detected for 1 s in 9.2.1.1, TONEq may be transmitted upon detection of ANSpcm. When ANSpcm is no longer detected, the modem shall terminate TONEq and transmit silence for 75 ± 5 ms and proceed to Phase 2 of the start-up procedure.

9.2.1.4 When ANSam is no longer detected the modem shall terminate TONEq and transmit silence for 75 ± 5 ms and proceed to Phase 2 of ITU-T V.34.

9.2.2 Call modem is digital modem

Initially, the call modem shall condition its receiver to detect signal ANSam as defined in ITU-T V.8 and optionally signal CRe as defined in ITU-T V.8 *bis*.

9.2.2.1 If signal ANSam is detected for 1 s, the digital modem shall transmit signal QC1d followed by CM and condition its receiver to detect QCA1a, JM and ANSam. If QCA1a is detected, the modem shall stop transmitting CM without completing the current octet and transmit silence for 75 ± 5 ms followed by QTS and QTS\ and then ANSpcm. The digital modem shall then proceed according to 9.2.2.3. If ANSam is detected for 1 s after sending QC1d, or JM is detected, the digital modem shall proceed according to ITU-T V.8.

9.2.2.2 If the initial 50 ms of signal CRe is detected, the digital modem shall transmit signal QC2d followed by silence and condition its receiver to detect QCA2a, ANSam and ANS. If QCA2a is detected, the modem shall transmit silence for 75 ± 5 ms followed by QTS, QTS\ and then ANSpcm and proceed according to 9.2.2.3. If ANSam is detected the modem shall proceed according to 9.2.2.1. If ANS is detected for 3 s after sending QC2d, the digital modem shall proceed according to ITU-T V.8. If QCA2a has not been detected 1 s after transmitting QC2a, the modem shall proceed in accordance with ITU-T V.8 *bis*.

9.2.2.3 When ANSpcm is transmitted, the modem shall condition its receiver to detect TONEq. When TONEq is detected, the modem shall transmit silence for 75 ± 5 ms and proceed to Phase 2 of the start-up procedure.

9.2.3 Answer modem is analogue modem

Upon connection to line, the modem shall initially remain silent for a minimum of 200 ms and then transmit signal ANSam according to the procedure specified in ITU-T V.8 or CRe according to the procedure specified in ITU-T V.8 *bis*.

9.2.3.1 If ANSam is transmitted, even when a previous V.8 *bis* session has timed out, the modem shall condition its receiver to detect either QC1d, QC1a or CM. If QC1d is detected, the modem shall transmit QCA1a followed by silence, and condition itself to detect QTS and QTS\ followed by ANSpcm and then proceed according to 9.2.3.3. If QC1a is detected, the modem may transmit QCA1a followed by silence for 75 ± 5 ms and then ANSam and proceed according to 9.2.3.4. If CM is detected, the modem shall proceed with normal V.8 procedures.

9.2.3.2 If CRe is transmitted, the modem shall condition its receiver to detect QC2d and V.8 *bis* signals. If QC2d is detected, the modem shall terminate transmission of CRe and shall transmit QCA2a followed by silence, and condition itself to detect QTS and QTS\ followed by ANSpcm and then proceed according to 9.2.3.3. If QC2a is detected, the modem may transmit QCA2a followed by silence for 75 ± 5 ms and then ANSam and proceed according to 9.2.3.4. If a V.8 *bis* signal other than QC2d or QC2a is detected, the modem shall proceed with normal V.8 *bis* procedures. If no V.8 *bis* signals nor QC2d or QC2a are detected 3 s after transmission of CRe, the analogue modem shall transmit ANSam and proceed according to 9.2.3.1.

9.2.3.3 When ANSpcm has been detected for 1 s, the modem shall transmit TONEq for a minimum of 50 ms; however, if ANSam was transmitted in 9.2.3.1 TONEq may be transmitted upon detection of ANSpcm. When ANSpcm is no longer detected, the modem shall terminate TONEq and transmit silence for 75 ± 5 ms and proceed to Phase 2 of the start-up procedure. If ANSpcm is not detected during the 2 s following transmission of QCA1a, the analogue modem shall transmit ANSam and proceed according to ITU-T V.8. If ANSpcm is not detected during the 2 s following transmission of QCA2a, the analogue modem shall transmit ANSam and proceed according to 9.2.3.1.

9.2.3.4 While transmitting ANSam, the modem shall condition its receiver to detect TONEq and CM. If CM is detected, the modem shall proceed according to ITU-T V.8. If TONEq is detected, the modem shall terminate ANSam, transmit silence for 75 ± 5 ms and proceed to Phase 2 of the start-up procedure.

9.2.4 Answer modem is digital modem

Upon connection to line, the modem shall initially remain silent for a minimum of 200 ms and then transmit signal ANSam according to the procedure specified in ITU-T V.8 or CRe according to the procedure specified in ITU-T V.8 *bis*.

9.2.4.1 If ANSam is transmitted, even when a previous V.8 *bis* session has timed out, the modem shall condition its receiver to detect QC1a, QC1d or CM. If QC1a is detected, the modem shall transmit QCA1d followed by silence for 75 ± 5 ms and then QTS, QTS\ and ANSpcm and proceed according to 9.2.4.3. If QC1d is detected, the modem may take on the role of the analogue modem and proceed according to 9.2.3.1. If CM is detected, the modem shall proceed with normal V.8 procedures.

9.2.4.2 If CRe is transmitted the modem shall condition its receiver to detect QC2a, QC2d and V.8 *bis* signals. If QC2a is detected, the modem shall terminate transmission of CRe and shall transmit QCA2d followed by silence for 75 ± 5 ms and then QTS, QTS\ and ANSpcm and proceed according to 9.2.4.3. If QC2d is detected, the modem may take on the role of the analogue modem and proceed according to 9.2.3.2. If a V.8 *bis* signal other than QC2a or QC2d is detected, the modem shall proceed with normal V.8 *bis* procedures. If no V.8 *bis* signals or QC2a or QC2d are detected 3 s after transmission of CRe, the digital modem shall transmit ANSam and proceed according to 9.2.4.1.

9.2.4.3 While ANSpcm is transmitted, the modem shall condition its receiver to detect TONEq. If TONEq is detected, the modem shall transmit silence for 75 ± 5 ms and proceed to Phase 2 of the start-up procedure. If TONEq is not detected during the 2 s following transmission of QCA1d, the digital modem shall transmit ANSam and proceed according to ITU-T V.8. If TONEq is not detected during the 2 s following transmission of QCA2d, the digital modem shall transmit ANSam and proceed according to 9.2.4.1.

9.2.5 ODP/ADP bypass

If both modems have indicated LAPM capability, the V.42 ODP/ADP exchange shall be bypassed.

9.3 Full Phase 2 – Probing/ranging

The operating procedures for full Phase 2 and the associated recovery procedures are identical to those for Phase 2 of ITU-T V.90. The information bits to be used for V.92 operation are defined in 8.4.1. If both the digital and analogue modems indicate V.92 capability using bit 27 of $INFO_{0d}$ and bit 26 of $INFO_{0a}$ respectively, then the digital modem shall use the information bits defined for $INFO_{1d}$ in 8.4.1. In this case, the analogue modem may select PCM upstream operation by using the information bits defined for $INFO_{1a}$ in Table 18. If either modem does not indicate V.92 capability, then the digital modem and analogue modem shall use the information bits defined in 8.2.3.2 of ITU-T V.90.

If both the digital and analogue modems indicate V.92 capability, any subsequent retrains shall use Phase 2 of ITU-T V.92.

9.3.1 ODP/ADP bypass

If both modems indicate V.92 capability as well as indicating LAPM protocol in ITU-T V.8 or ITU-T V.8 *bis*, then the V.42 ODP/ADP exchange shall be bypassed.

9.4 Short Phase 2 – Ranging

If both the digital and analogue modems indicate V.92 capability and the desire to shorten Phase 2 by using bit 26 of $INFO_{0d}$ and bit 27 of $INFO_{0a}$ respectively, then the modems shall proceed as described below. The analogue modem shall only indicate the desire to use a short Phase 2 if it intends to connect in either PCM upstream or V.90 data mode.

The error-free operation of short Phase 2 is illustrated in Figure 9.

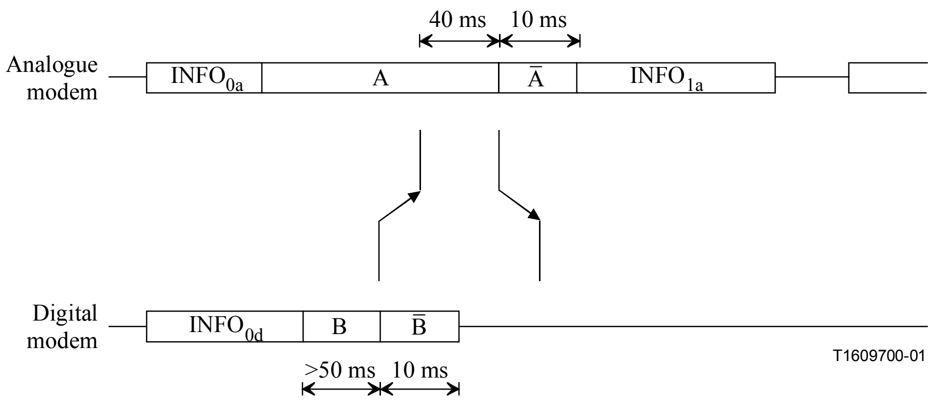


Figure 9/V.92 – Short Phase 2 – Ranging

9.4.1 Digital modem

9.4.1.1 Error-free procedures

9.4.1.1.1 During the 75 ± 5 ms silent period ending Phase 1, the digital modem shall condition its receiver to receive $INFO_{0a}$ and detect Tone A. After the 75 ± 5 ms silent period, the digital modem shall send $INFO_{0d}$ with bit 28 set to 0, followed by Tone B.

9.4.1.1.2 After receiving $INFO_{0a}$, the digital modem shall condition its receiver to detect Tone A and receive $INFO_{0a}$ (see 9.4.1.2).

9.4.1.1.3 After Tone A has been detected and Tone B has been transmitted for at least 50 ms, the digital modem shall transmit a Tone B phase reversal. Tone B shall be transmitted for another 10 ms after the phase reversal. The digital modem shall then transmit silence and condition its receiver to detect a Tone A phase reversal.

9.4.1.1.4 After detecting the Tone A phase reversal, the digital modem has the information required to calculate the round-trip delay. The round-trip delay estimate, RTDEd, is the time interval between the appearance of the Tone B phase reversal at the digital modem line terminals and receiving the Tone A phase reversal at the line terminals minus 40 ms. The digital modem shall then transmit silence and condition its receiver to receive $INFO_{1a}$.

9.4.1.1.5 After receiving $INFO_{1a}$, the digital modem shall proceed in accordance with the appropriate Phase 3 as signalled in $INFO_{1a}$.

9.4.1.2 Recovery procedures

9.4.1.2.1 If, in 9.4.1.1.2 or in 9.4.1.1.3, the digital modem detects Tone A before correctly receiving $INFO_{0a}$, or if it receives repeated $INFO_{0a}$ sequences, the digital modem shall repeatedly send $INFO_{0d}$ sequences. The digital modem shall set bit 28 of the $INFO_{0d}$ sequence to 1 after correctly receiving $INFO_{0a}$. If the digital modem receives $INFO_{0a}$ with bit 28 set to 1, it shall condition its receiver to detect Tone A and a subsequent Tone A phase reversal, complete sending the current $INFO_{0d}$ sequence, and then transmit Tone B. Alternatively, if the digital modem detects Tone A and has correctly received $INFO_{0a}$, it shall condition its receiver to detect Tone A phase reversal, complete sending the current $INFO_{0d}$ sequence, and then transmit Tone B. In both cases, the digital modem shall then proceed according to 9.4.1.1.3.

9.4.1.2.2 If, in 9.4.1.1.4, the digital modem does not detect a Tone A phase reversal within 2500 ms from transmission of the Tone B phase reversal in 9.4.1.1.3, the digital modem shall condition its receiver to detect Tone A. Upon detection of Tone A, the digital modem shall transmit Tone B and condition its receiver to detect Tone A phase reversal. The digital modem shall then proceed with the full Phase 2 procedure.

9.4.1.2.3 If, in 9.4.1.1.5, the digital modem does not receive $INFO_{1a}$ within 2500 ms from the transmission of Tone B phase reversal in 9.4.1.1.3, the digital modem shall send Tone B and condition its receiver to detect Tone A. Upon detection of Tone A, the digital modem shall condition its receiver to detect the Tone A phase reversal and proceed with the full Phase 2 procedure.

9.4.2 Analogue modem

9.4.2.1 Error-free procedures

9.4.2.1.1 During the 75 ± 5 ms silent period ending Phase 1, the analogue modem shall condition its receiver to receive $INFO_{0d}$ and detect Tone B. After the 75 ± 5 ms silent period, the analogue modem shall send $INFO_{0a}$ with bit 28 set to 0, followed by Tone A.

9.4.2.1.2 After receiving $INFO_{0d}$, the analogue modem shall condition its receiver to detect Tone B and receive $INFO_{0d}$ (see 9.4.2.2) and detect the subsequent Tone B phase reversal.

9.4.2.1.3 After detecting the Tone B phase reversal, the analogue modem shall transmit a Tone A phase reversal. The Tone A phase reversal shall be delayed so that the time duration between receiving the Tone B phase reversal at the line terminals and the appearance of the Tone A phase reversal at the line terminals is 40 ± 1 ms. Tone A shall be transmitted for 10 ms after the phase reversal.

9.4.2.1.4 Then, the analogue modem shall send $INFO_{1a}$ and proceed in accordance with the appropriate Phase 3 as signalled in $INFO_{1a}$.

9.4.2.2 Recovery procedures

9.4.2.2.1 If, in 9.4.2.1.2 or in 9.4.2.1.3, the analogue modem detects Tone B before correctly receiving $INFO_{0d}$, or if it receives repeated $INFO_{0d}$ sequences, the analogue modem shall repeatedly send $INFO_{0a}$ sequences. The analogue modem shall set bit 28 of the $INFO_{0a}$ sequence to 1 after correctly receiving $INFO_{0d}$. If the analogue modem receives $INFO_{0d}$ with bit 28 set to 1, it shall condition its receiver to detect Tone B, complete sending the current $INFO_{0a}$ sequence, and then transmit Tone A. Alternatively, if the analogue modem detects Tone B and has correctly received $INFO_{0d}$, it shall complete sending the current $INFO_{0a}$ sequence, and transmit Tone A. In both cases, the analogue modem shall then proceed according to 9.4.2.1.3.

9.4.2.2.2 If, in 9.4.2.1.3, the analogue modem does not detect the Tone B phase reversal within 2500 ms from the end of $INFO_{0a}$ transmission, the analogue modem shall initiate a retrain according to 9.7.2.1.

9.5 Phase 3 – Equalizer and echo canceller training and digital impairment learning

See Figures 10 and 11.

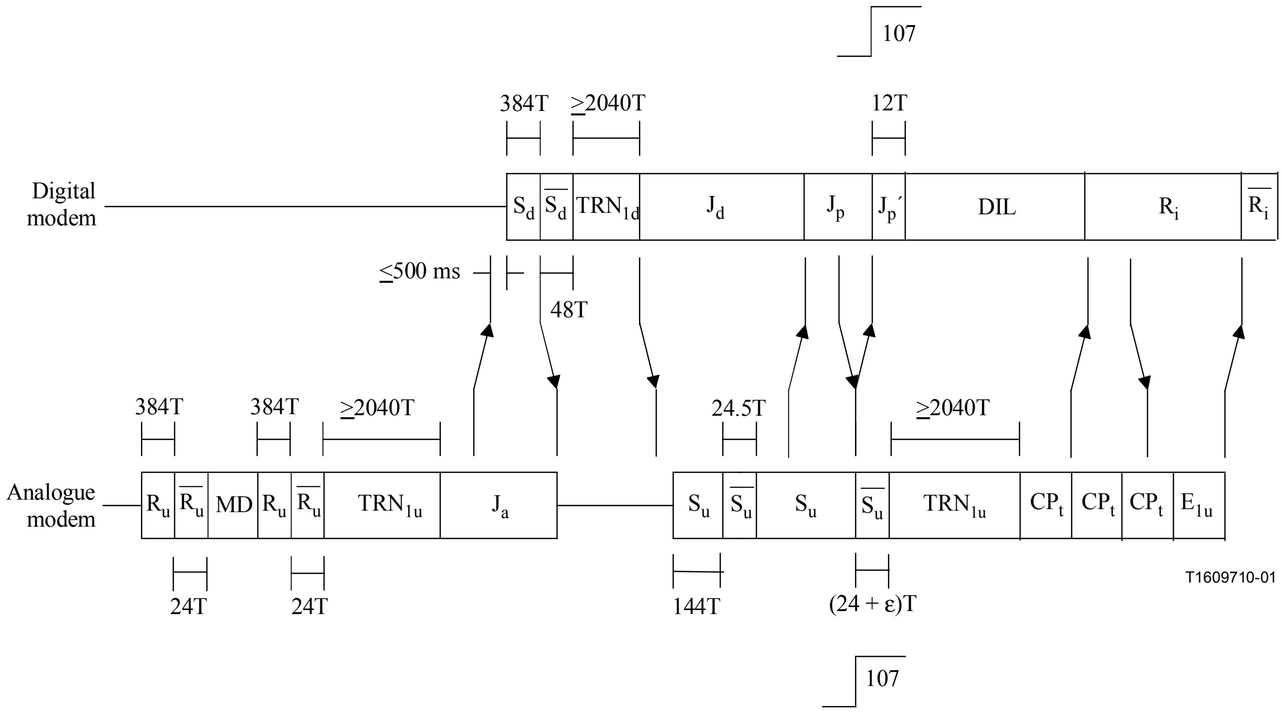


Figure 10/V.92 – Phase 3 – Equalizer and echo canceller training and digital impairment learning

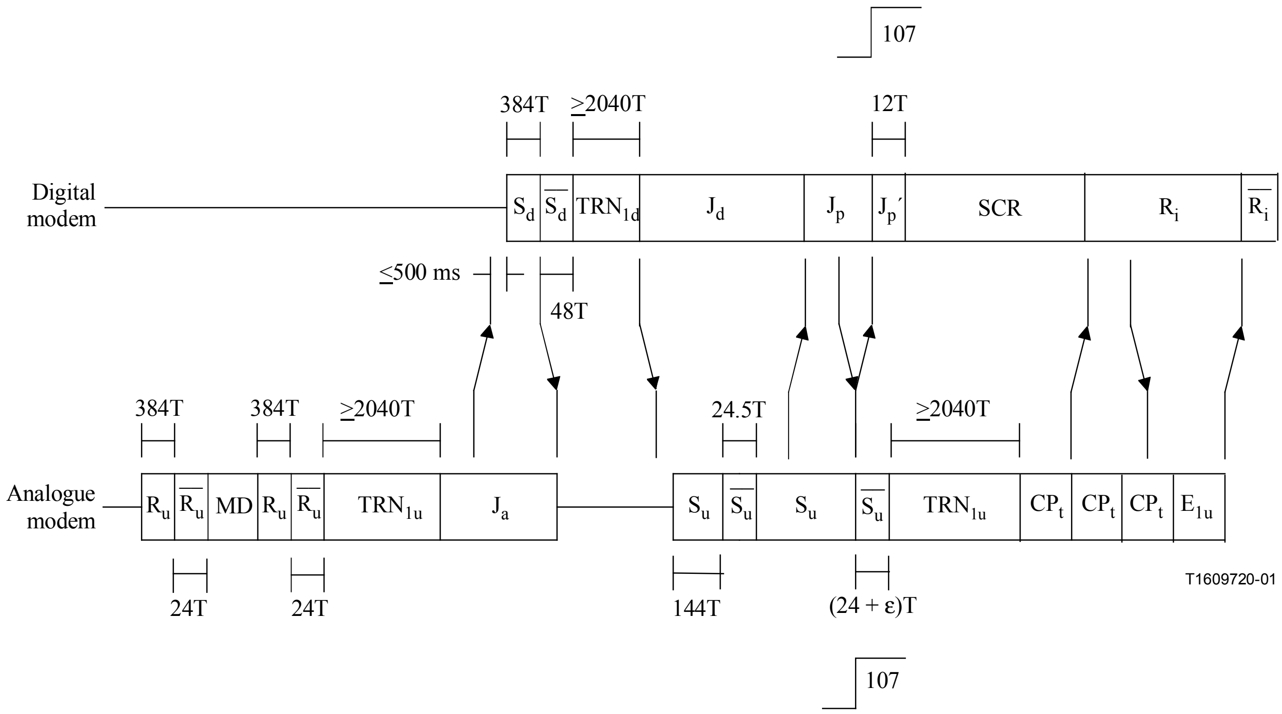


Figure 11/V.92 – Phase 3 – Equalizer and echo canceller training when no DIL has been requested

9.5.1 Digital modem

9.5.1.1 Error-free procedures

9.5.1.1.1 The digital modem shall be initially silent and condition its receiver to detect R_u and the subsequent $\overline{R_u}$. If the duration of signal MD indicated by $INFO_{1a}$ is zero, the digital modem shall proceed according to 9.5.1.1.2. Otherwise, after detecting the R_u-to-$\overline{R_u}$ transition, the digital modem shall wait for the duration of signal MD as indicated by $INFO_{1a}$ and then shall condition its receiver to receive signal R_u and the subsequent R_u-to-$\overline{R_u}$ transition.

9.5.1.1.2 After detecting signal R_u and the R_u-to-$\overline{R_u}$ transition, the digital modem shall condition its receiver to begin training its equalizer using signal TRN_{1u}.

9.5.1.1.3 After receiving the first 2040T of signal TRN_{1u}, the digital modem shall condition its receiver to receive sequence J_a. After receiving a DIL descriptor of J_a, the digital modem may wait for up to 500 ms and shall then transmit signal S_d for 384T and signal $\overline{S_d}$ for 48T.

9.5.1.1.4 The digital modem shall then transmit TRN_{1d} for a minimum of 2040T. Within 4000 ms of starting to transmit TRN_{1d} the digital modem shall transmit J_d and condition its receiver to detect signal S_u.

9.5.1.1.5 The digital modem shall continue to repeat the J_d sequence.

9.5.1.1.6 Upon detection of S_u digital modem shall condition its receiver to detect the S_u-to-$\overline{S_u}$ transition. It should use signal S_u to measure the phase information.

9.5.1.1.7 Upon detection of S_u-to-$\overline{S_u}$ the digital modem shall condition its receiver to continue receiving signal S_u and should continue to measure the phase information.

9.5.1.1.8 Once the digital modem has determined the proper phase adjustment it shall complete the current J_d sequence and then transmit the J_p sequence and condition its receiver to detect the S_u-to-$\overline{S_u}$ transition.

9.5.1.1.9 Upon detection of the S_u-to-$\overline{S_u}$ transition, the digital modem shall complete the current J_p sequence, assert circuit 107 and then transmit J_p'.

9.5.1.1.10 The digital modem shall then receive TRN_{1u}. The digital modem shall keep a modulo 12 data frame interval count from the first symbol of TRN_{1u}.

9.5.1.1.11 After sending J_p', the digital modem shall send the DIL requested by the analogue modem and condition its receiver to receive CP_t. If the analogue modem requested a DIL of zero length then the digital modem shall send SCR instead of DIL and proceed according to 9.5.1.1.13.

9.5.1.1.12 Upon receiving CP_t, the digital modem shall transmit R_i. Upon receiving the E_{1u} terminating the CP_t sequences, the digital modem shall transmit $\overline{R_i}$ and then proceed to Phase 4 of the start-up procedure.

9.5.1.1.13 When the digital modem is sufficiently trained, it shall transmit R_i and condition its receiver to receive CP_t. Upon receiving CP_t, the digital modem shall transmit $\overline{R_i}$ and then proceed to Phase 4 of the start-up procedure.

9.5.1.2 Recovery procedures

The digital modem may initiate a retrain at any time during Phase 3 according to 9.7.1.1. If Tone A is detected during Phase 3, the digital modem shall respond to retrain according to 9.7.1.2.

9.5.1.2.1 If, in 9.5.1.1.3, the digital modem does not detect J_a within 4500 ms plus a round-trip delay from the end of $INFO_{1a}$ the digital modem shall initiate a retrain according to 9.7.1.1

9.5.1.2.2 If, in 9.5.1.1.9, the digital modem does not detect S_u within 5100 ms plus a round-trip delay from the start of TRN_{1d}, the digital modem shall initiate a retrain according to 9.7.1.1.

9.5.2 Analogue modem

9.5.2.1 Error-free procedures

9.5.2.1.1 After sending sequence $INFO_{1a}$, the analogue modem shall transmit silence for 70 ± 5 ms, signal R_u for 384T and signal $\overline{R_u}$ for 24T. If the duration of the analogue modem's MD signal, as indicated in the $INFO_{1a}$, is zero, the modem shall proceed according to 9.5.2.1.2. Otherwise, the modem shall transmit signal MD for the duration indicated in $INFO_{1a}$, signal R_u for 384T and signal $\overline{R_u}$ for 24T.

9.5.2.1.2 The analogue modem shall then transmit signal TRN_{1u}. Signal TRN_{1u} shall be transmitted for at least 2040T. The total time from the beginning of transmission of signal MD to the end of signal TRN_{1u} shall not exceed one round-trip delay plus 4000 ms.

9.5.2.1.3 After transmitting signal TRN_{1u}, the modem shall send sequence J_a and condition its receiver to detect signal S_d and the S_d-to-$\overline{S_d}$ transition. After detecting the S_d-to-$\overline{S_d}$ transition, the modem shall terminate J_a at the next 12 bit boundary and transmit silence.

9.5.2.1.4 The modem shall condition its receiver to begin its equalizer training using the first 2040T of signal TRN_{1d}.

9.5.2.1.5 After receiving 2040T of signal TRN_{1d}, the analogue modem shall condition its receiver to receive sequence J_d.

9.5.2.1.6 After receiving J_d, the analogue modem may wait for up to 5000 ms from having begun to transmit silence as required in the procedure in 9.5.2.1.3 and shall then transmit signal S_u for 144T.

9.5.2.1.7 After transmitting 144T of signal S_u the analogue modem shall transmit signal $\overline{S_u}$ for length of 24.5T followed by signal S_u and condition its receiver to detect J_p.

9.5.2.1.8 After detecting J_p, the analogue modem shall assert circuit 107 and transmit $\overline{S_u}$ for 24T plus any fractional amount from 0 to 1 symbol as specified in J_p and shall condition its receiver to detect J_p'.

9.5.2.1.9 After detecting J_p' the analogue modem shall then condition its receiver to receive the DIL sequence it requested in J_a or SCR if it requested a DIL of zero length. During the reception of DIL or SCR the analogue modem shall transmit TRN_{1u}. The length for this segment of TRN_{1u} shall be in multiple of 12 symbols and shall be at least 2040T long if a non-zero DIL was requested.

9.5.2.1.10 If the analogue modem has requested a zero length DIL, it shall wait until it receives R_i and then transmit CP_t sequences. Upon receiving $\overline{R_i}$, the analogue modem shall complete sending the current CP_t, transmit E_{1u} and then proceed to Phase 4 of the start-up procedure.

9.5.2.1.11 If the analogue modem requested a non-zero length DIL, it shall transmit at least 2040T of TRN_{1u} followed by CP_t within 5000 ms of transmitting $\overline{S_u}$ in 9.5.2.1.8. This indicates to the digital modem that the analogue modem has received enough of the DIL sequence. The analogue modem shall continue to send CP_t sequences until it receives R_i. Upon receiving R_i, the analogue modem shall complete sending the current CP_t, transmit E_{1u} and then proceed to Phase 4 of the start-up procedure.

9.5.2.2 Recovery procedures

The analogue modem may initiate a retrain at any time during Phase 3 according to 9.7.2.1. If Tone B is detected during Phase 3, the analogue modem shall respond to retrain according to 9.7.2.2.

9.5.2.2.1 If, in 9.5.2.1.3, the analogue modem does not detect the S_d-to-$\overline{S_d}$ transition within 1500 ms from the start of J_a, the analogue modem shall initiate a retrain according to 9.7.2.1.

9.5.2.2.2 If, in 9.5.2.1.6, the analogue modem does not receive J_d within 4500 ms from the end of J_a, the analogue modem shall initiate a retrain according to 9.7.2.1.

9.6 Phase 4 – Final training

See Figures 12 to 14.

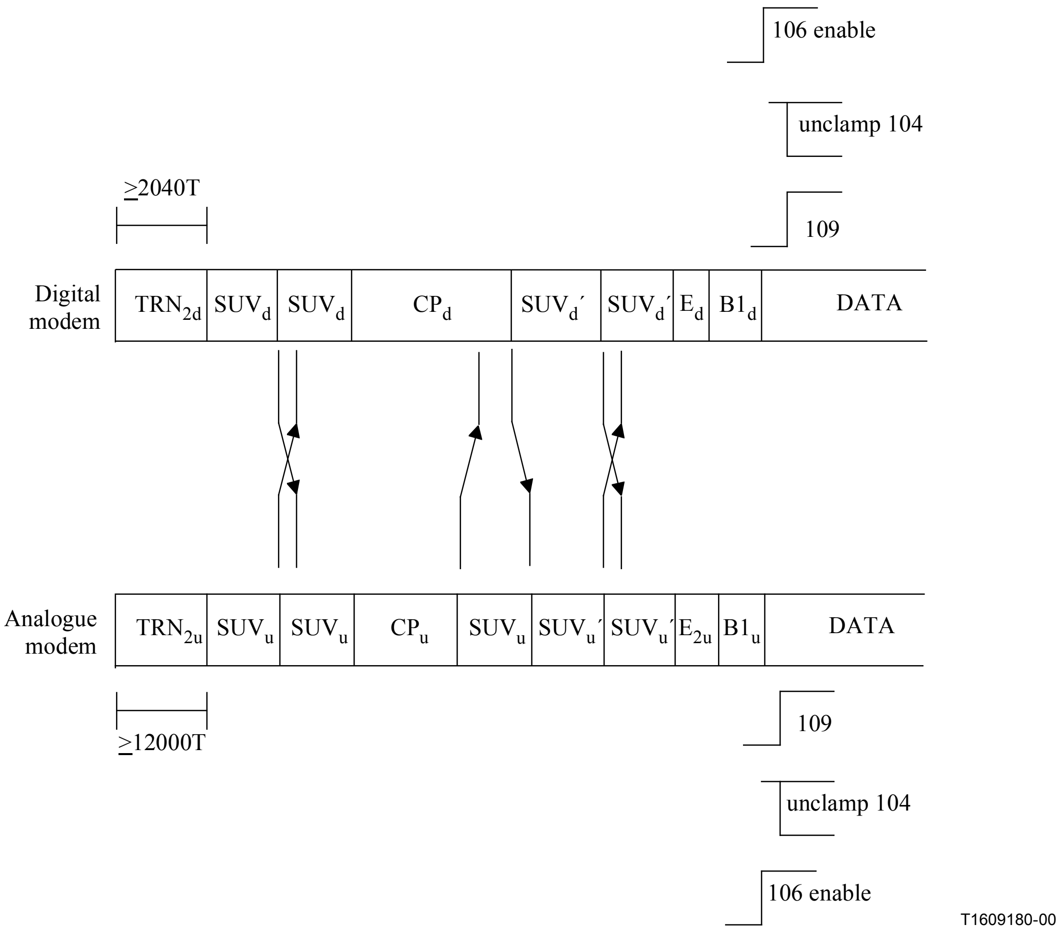


Figure 12/V.92 – Phase 4 – Final training where the two CP sequences occur at about the same time

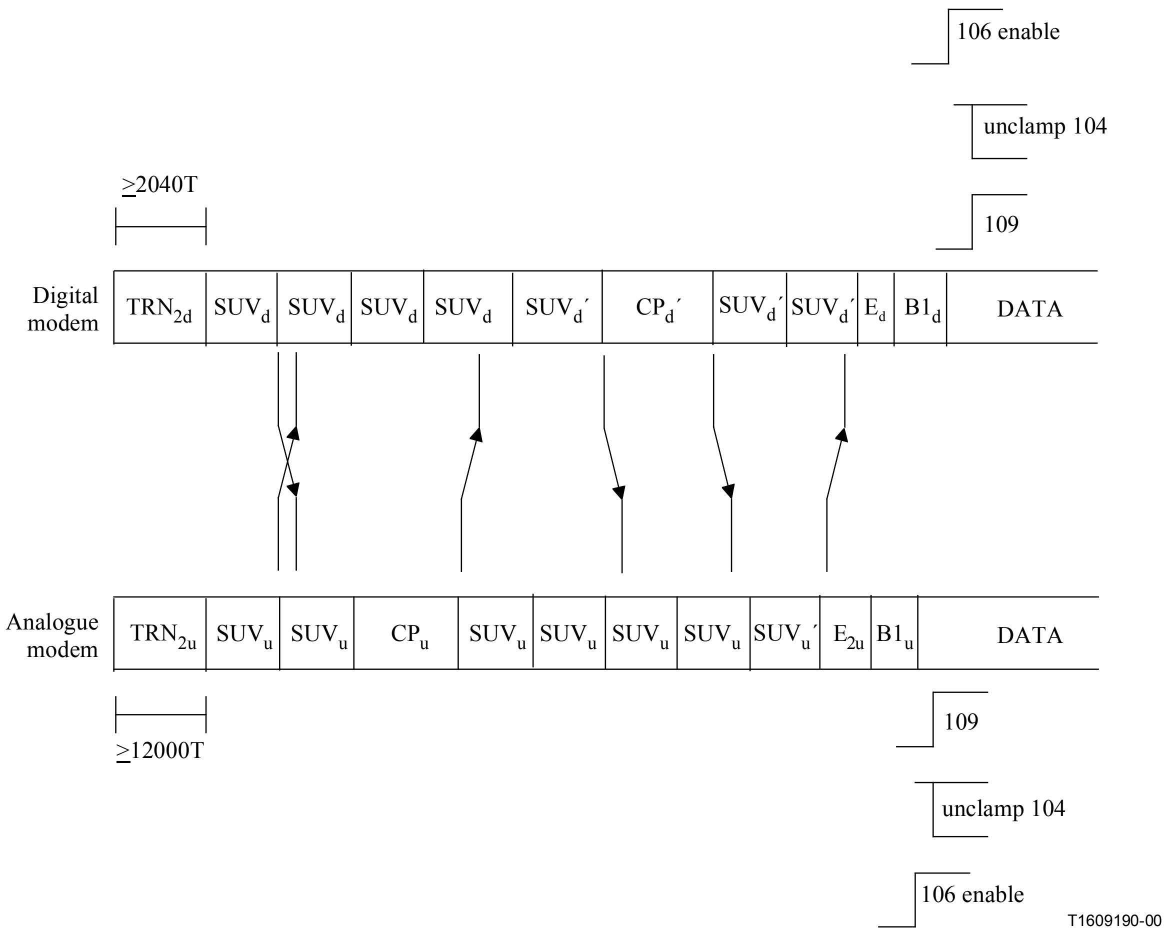


Figure 13/V.92 – Phase 4 – Final training where CP_u is sent earlier than CP_d

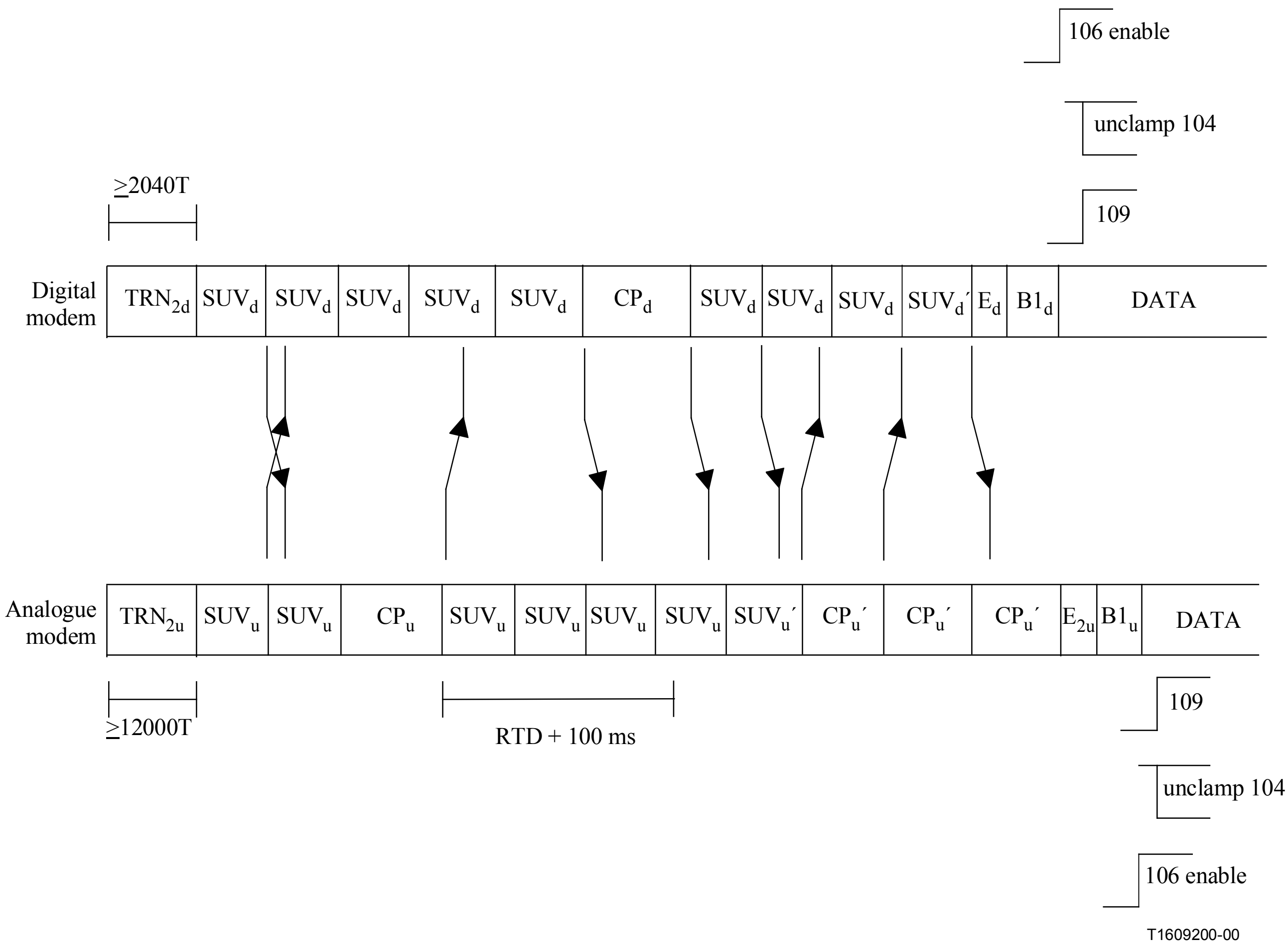


Figure 14/V.92 – Phase 4 – Final training where the first CP_u is not received by the digital modem

9.6.1 Digital modem

9.6.1.1 Error-free procedures

9.6.1.1.1 The digital modem shall transmit TRN_{2d} for at least 2040T. When the digital modem is ready to receive a CP_u sequence, it shall condition its receiver to receive an SUV_u sequence and it shall transmit SUV_d sequences.

9.6.1.1.2 After receiving an SUV_u sequence, the digital modem shall transmit a single CP_d sequence followed by more SUV_d sequences. After receiving a CP_u sequence, the digital modem shall transmit subsequent CP_d and SUV_d sequences with the acknowledgement bit set.

9.6.1.1.3 If the acknowledgement bit is not set in any of the CP_u or SUV_u sequences received by the digital modem up to and including the entire CP_u or SUV_u sequence that is received after 100 ms plus a round-trip delay from the end of its CP_d, the digital modem shall send repeated CP_d sequences.

9.6.1.1.4 After the digital modem has sent a CP_d or SUV_d sequence with the acknowledgement bit set and it has received a CP_u or SUV_u sequence with the acknowledgement bit set or E_{2u}, the digital modem shall complete sending the current CP_d or SUV_d sequence and transmit E_d.

9.6.1.1.5 After sending the E_d sequence, the digital modem shall send $B1_d$ at the negotiated data signalling rate using the data mode constellation parameters it received in CP_u. The modem shall then enable circuit 106 to respond to the condition of circuit 105 and begin data transmission using the modulation procedures of clause 5.

9.6.1.1.6 After receiving E_{2u}, the digital modem shall condition its receiver to receive $B1_u$, or for a Fast Parameter Exchange, condition its receiver to receive $FB1_u$ followed by $B1_u$. After receiving $B1_u$, the digital modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

9.6.1.2 Recovery procedures

The digital modem may initiate a retrain at any time during Phase 4 according to 9.7.1.1. If Tone A is detected during Phase 4, the digital modem shall respond to retrain according to 9.7.1.2.

9.6.1.2.1 If the digital modem does not receive $B1_u$ within 20 s plus 6 round-trip delays from the end of $INFO_{1a}$, the digital modem shall initiate a retrain according to 9.7.1.1.

9.6.2 Analogue modem

9.6.2.1 Error-free procedures

9.6.2.1.1 The analogue modem shall condition its receiver to receive an SUV_d sequence and transmit TRN_{2u}. When the analogue modem is ready to receive a CP_d sequence and it has transmitted TRN_{2u} for at least 12000T or received an SUV_d sequence, it shall transmit SUV_u sequences.

9.6.2.1.2 After receiving an SUV_d sequence, the analogue modem shall transmit a single CP_u sequence followed by more SUV_u sequences. After receiving a CP_d sequence, the analogue modem shall transmit subsequent CP_u and SUV_u sequences with the acknowledgement bit set.

9.6.2.1.3 If the acknowledgement bit is not set in any of the CP_d or SUV_d sequences received by the analogue modem up to and including the entire CP_d or SUV_d sequence that is received after 100 ms plus a round-trip delay from the end of its CP_u, the analogue modem shall send repeated CP_u sequences.

9.6.2.1.4 After the analogue modem has sent a CP_u or SUV_u sequence with the acknowledgement bit set and it has received a CP_d or SUV_d sequence with the acknowledgement bit set or E_d, the analogue modem shall complete sending the current CP_u sequence and transmit E_{2u}.

9.6.2.1.5 After sending the E_{2u} sequence, the analogue modem shall send either $B1_u$, or, for Fast Parameter Exchange, $FB1_u$ followed by $B1_u$. The modem shall then enable circuit 106 to respond to the condition of circuit 105 and begin data transmission using the modulation procedures of 6.4.

9.6.2.1.6 After receiving E_d, the analogue modem shall condition its receiver to receive $B1_d$. After receiving $B1_d$, the analogue modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

9.6.2.2 Recovery procedures

The analogue modem may initiate a retrain at any time during Phase 4 according to 9.7.2.1. If Tone B is detected during Phase 4, the analogue modem shall respond to retrain according to 9.7.2.2.

9.6.2.2.1 If the analogue modem does not receive $B1_d$,within 20 s plus 6 round-trip delays from the end of sending $INFO_{1a}$, the analogue modem shall initiate a retrain according to 9.7.2.1.

9.7 Retrains

9.7.1 Digital modem

9.7.1.1 Initiating retrain

To initiate a retrain, the digital modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The digital modem shall then transmit Tone B and condition its receiver to detect Tone A. After detecting Tone A, the digital modem shall condition its receiver to detect a Tone A phase reversal and proceed in accordance with the full Phase 2 start-up procedure.

9.7.1.2 Responding to retrain

After detecting Tone A for more than 50 ms, the digital modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The digital modem shall then transmit Tone B, condition its receiver to detect a Tone A phase reversal, and proceed in accordance with the full Phase 2 start-up procedure.

9.7.2 Analogue modem

9.7.2.1 Initiating retrain

To initiate a retrain, the analogue modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The analogue modem shall then transmit Tone A and condition its receiver to detect Tone B. After detecting Tone B and when Tone A has been transmitted for at least 50 ms, the analogue modem shall transmit a Tone A phase reversal, condition its receiver to detect a Tone B phase reversal and proceed in accordance with the full Phase 2 start-up procedure.

9.7.2.2 Responding to retrain

After detecting Tone B for more than 50 ms, the analogue modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The analogue modem shall then transmit Tone A and proceed in accordance with the full Phase 2 start-up procedure.

9.8 Rate renegotiation

The rate renegotiation procedure can be initiated at any time during data mode (see Figures 15 to 18). Data signalling rate and other parameters may change as a result of rate renegotiation. This procedure can also be used to retrain the analogue modem's echo canceller or the precoder and prefilter without going through a complete retrain.

The digital modem and the analogue modem shall maintain data frame synchronization during rate renegotiation. Rate renegotiation shall be initiated only on the boundary of a data frame. Similarly, a modem shall only respond to a rate renegotiation on the boundary of a data frame.

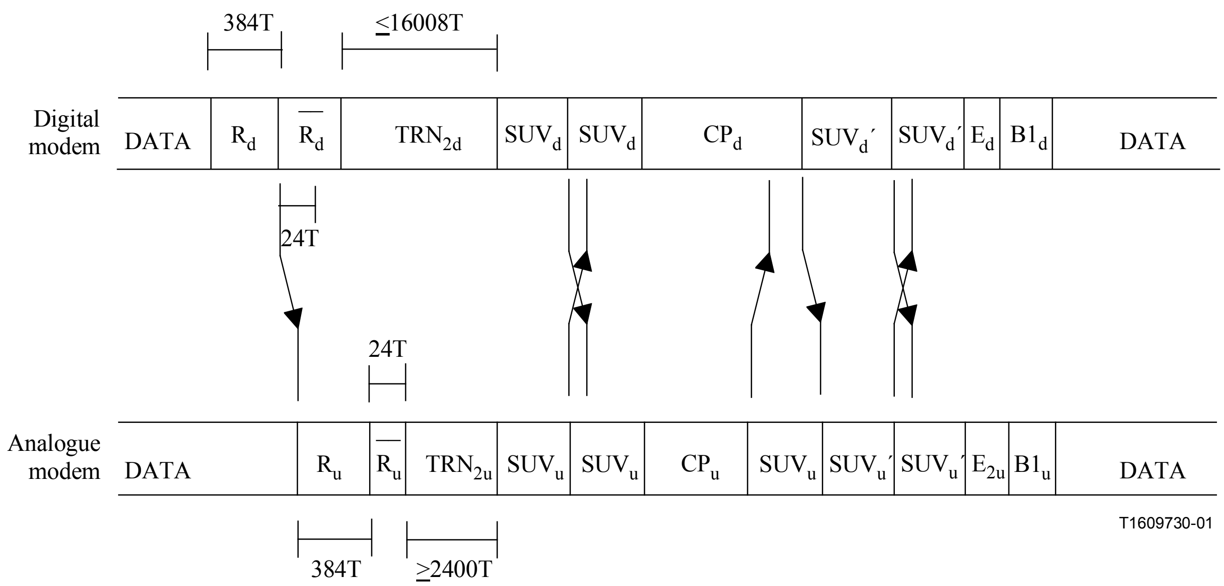


Figure 15/V.92 – Rate renegotiation with no silence initiated by the digital modem

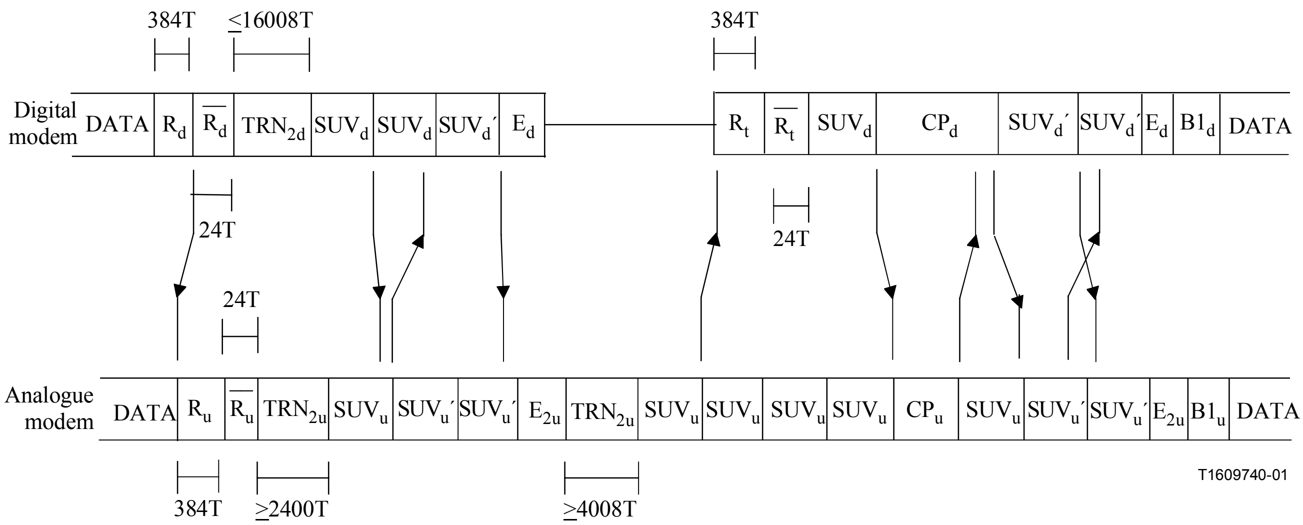


Figure 16/V.92 – Rate renegotiation with silence requested by the digital modem and sustained for the maximum length

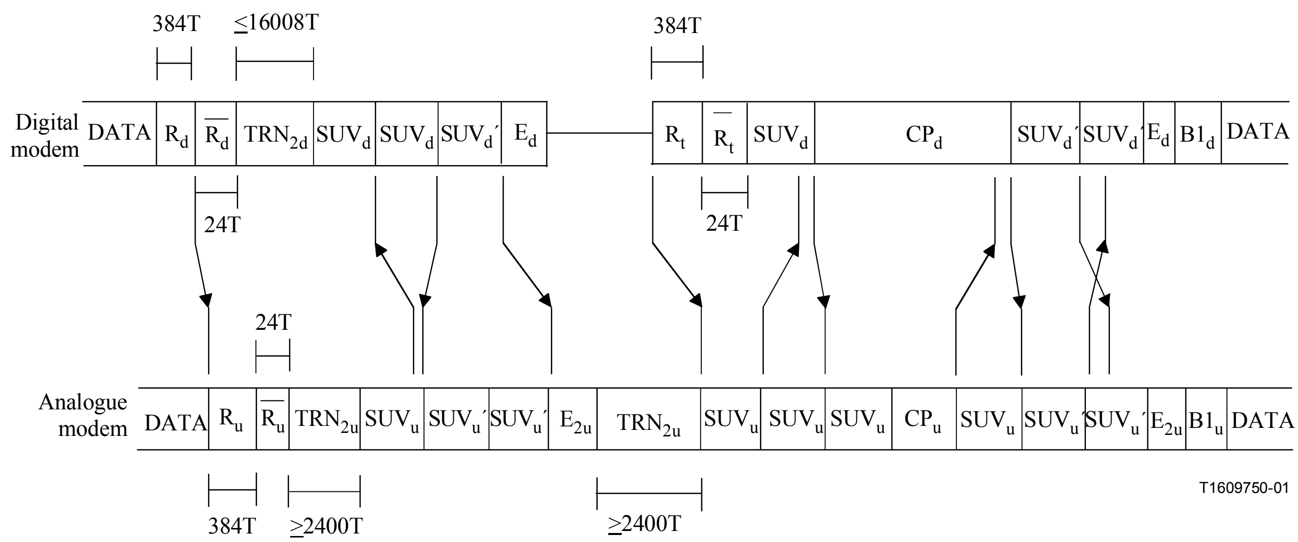


Figure 17/V.92 – Rate renegotiation with silence requested by the digital modem and terminated before maximum length

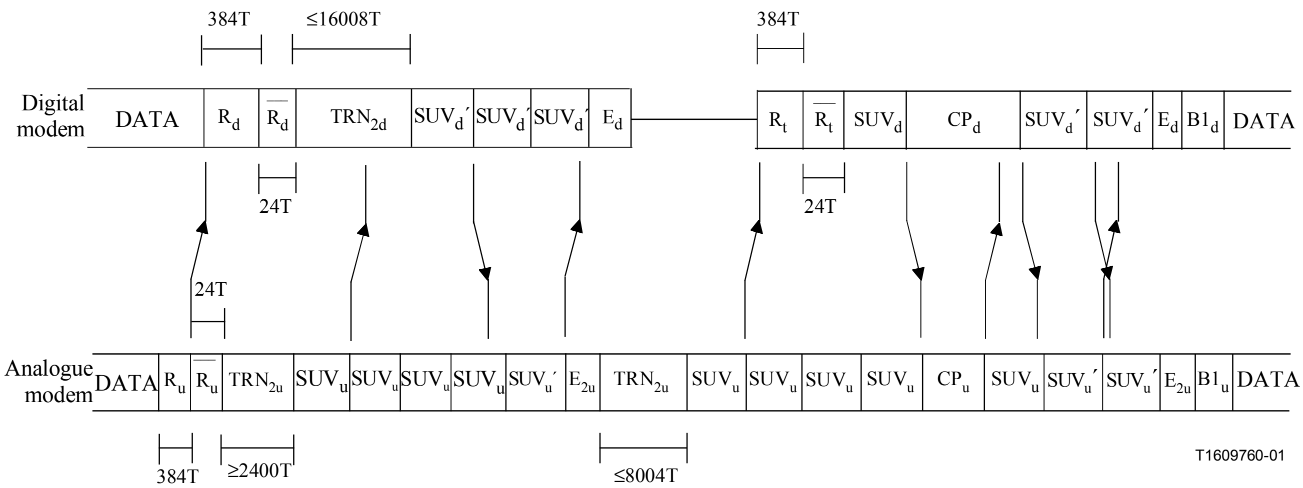


Figure 18/V.92 – Rate renegotiation with silence requested by the analogue modem

9.8.1 Digital modem

9.8.1.1 Initiating a rate renegotiation

9.8.1.1.1 The digital modem shall turn OFF circuit 106, condition its receiver to detect R_u, $\overline{R_u}$, and SUV_u and transmit signal R_d for 384T and then $\overline{R_d}$ for 24T. The signal R_d shall begin on the boundary of a data frame.

9.8.1.1.2 The digital modem shall then transmit TRN_{2d} for up to 16008T followed by SUV_d sequences. Upon receiving an SUV_u sequence, the digital modem shall proceed according to 9.6.1.1.2 unless bit 32 is set in either SUV_d or SUV_u.

9.8.1.1.3 The digital modem shall then transmit SUV_d sequences with bit 33 set. After receiving an SUV_u sequence with bit 33 set or E_{2u}, the digital modem shall complete sending the current SUV_d and then transmit E_d followed by silence. The digital modem shall generate silence by sending PCM codewords with magnitudes represented by Ucode 0. It shall retain data frame alignment during this period of silence.

9.8.1.1.4 If bit 32 of SUV_u was set, the digital modem shall wait to receive SUV_u with bit 32 clear. After receiving SUV_u with bit 32 clear, the digital modem shall transmit R_t for 384T followed by $\overline{R_t}$ for 24T and SUV_d. The digital modem shall then proceed according to 9.6.1.1.2.

9.8.1.1.5 If bit 32 of SUV_u was clear, the digital modem may transmit R_t for 384T followed by $\overline{R_t}$ for 24T and SUV_d sequences or wait to receive another SUV_u. The digital modem shall then proceed according to 9.6.1.1.2.

9.8.1.2 Responding to a rate renegotiation

9.8.1.2.1 After detecting R_u, the digital modem shall clamp circuit 104 to binary one and condition its receiver to detect the R_u-to-$\overline{R_u}$ transition.

9.8.1.2.2 After detecting the R_u-to-$\overline{R_u}$ transition, the digital modem shall transmit signal R_d for 384T and then $\overline{R_d}$ for 24T. The signal R_d shall begin on the boundary of a data frame.

9.8.1.2.3 The digital modem shall then proceed according to 9.8.1.1.2.

9.8.2 Analogue modem

9.8.2.1 Initiating a rate renegotiation

9.8.2.1.1 The analogue modem shall turn OFF circuit 106, transmit signal R_u for 384T followed by $\overline{R_u}$ for 24T. The signal R_u shall begin on the boundary of a data frame.

9.8.2.1.2 The analogue modem shall condition its receiver to receive an SUV_d sequence. The analogue modem shall transmit TRN_{2u} for up to 16008T, but it may terminate the transmission of TRN_{2u} after 2400T or when SUV_d is received.

9.8.2.1.3 The analogue modem shall then transmit SUV_u sequences. After transmitting an SUV_u sequence and receiving an SUV_d sequence the analogue modem shall proceed according to 9.6.2.1.2 unless bit 32 is set in either SUV_u or SUV_d.

9.8.2.1.4 The analogue modem shall then transmit SUV_u sequences with bit 33 set. After receiving an SUV_d sequence with bit 33 set or E_d, the analogue modem shall complete sending the current SUV_u and then transmit E_{2u} followed by TRN_{2u}.

9.8.2.1.5 If bit 32 of SUV_d was clear, the analogue modem shall transmit TRN_{2u} for up to 8004T followed by SUV_u with bit 32 clear. The analogue modem shall then proceed according to 9.6.2.1.2.

9.8.2.1.6 If bit 32 of SUV_d was set, the analogue modem shall condition its receiver to receive R_t. Upon receiving R_t or after transmitting 8004T of TRN_{2u}, the analogue modem shall transmit SUV_u sequences with bit 32 clear and wait to receive an SUV_d. The analogue modem shall then proceed according to 9.6.2.1.2.

9.8.2.2 Responding to a rate renegotiation

9.8.2.2.1 After receiving R_d, the analogue modem shall clamp circuit 104 to binary one and shall condition its receiver to detect the R_d-to-$\overline{R_d}$ transition.

9.8.2.2.2 After receiving the R_d-to-$\overline{R_d}$ transition, the analogue modem transmit R_u for 384T and $\overline{R_u}$ for 24T. The signal R_u shall begin on the boundary of a data frame.

9.8.2.2.3 The analogue modem shall condition its receiver to receive an SUV_d sequence. The analogue modem shall transmit TRN_{2u} for up to 16008T, but it may terminate the transmission of TRN_{2u} after 2400T or when SUV_d is received and proceed according to 9.8.2.1.3.

9.9 Fast parameter exchange

The fast parameter exchange procedure can be initiated at any time during data mode (see Figure 19). Data signalling rate and other parameters may change as a result of a fast parameter exchange.

The digital modem and the analogue modem shall maintain data frame synchronization during a fast parameter exchange. A fast parameter exchange shall be initiated only on the boundary of a data frame. Similarly, a modem shall only respond to a fast parameter exchange on the boundary of a data frame.

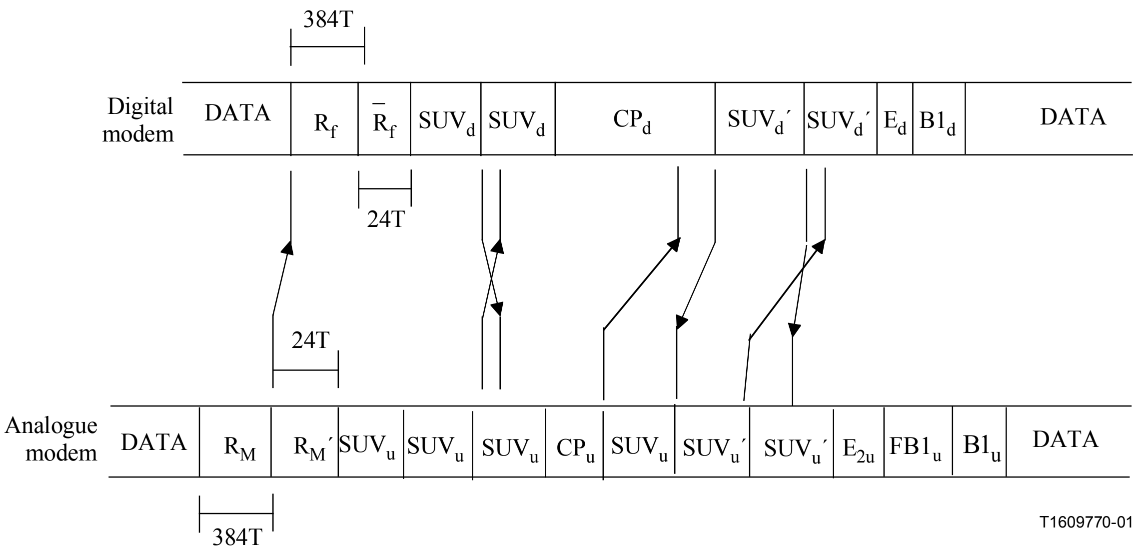


Figure 19/V.92 – Fast parameter exchange initiated by the analogue modem

9.9.1 Digital modem

9.9.1.1 Initiating a fast parameter exchange

9.9.1.1.1 The digital modem shall turn OFF circuit 106, condition its receiver to detect R_M, R_M' and SUV_u and transmit signal R_f for 384T followed by $\overline{R_f}$ for 24T. The signal R_f shall begin on the boundary of a data frame.

9.9.1.1.2 The digital modem shall then initialize the scrambler, differential encoder and spectral shaping filter memory to zero and transmit SUV_d sequences with bit 32 clear and, after detecting R_M, R_M', condition its receiver to receive an SUV_u sequence and proceed according to 9.6.1.1.2. If signal R_u is detected the modem shall proceed according to 9.8.1.2.1.

9.9.1.2 Responding to a fast parameter exchange

9.9.1.2.1 After detecting R_M, the digital modem shall clamp circuit 104 to binary one and condition its receiver to detect the R_M-to-R_M' transition.

9.9.1.2.2 After detecting the R_M-to-R_M' transition, the digital modem shall transmit signal R_f for 384T and then $\overline{R_f}$ for 24T. The signal R_f shall begin on the boundary of a data frame.

9.9.1.2.3 The digital modem shall then initialize the scrambler, differential encoder and spectral shaping filter memory to zero and transmit SUV_d sequences with bit 32 clear and proceed according to 9.6.1.1.2.

9.9.2 Analogue modem

9.9.2.1 Initiating a fast parameter exchange

9.9.2.1.1 The analogue modem shall turn OFF circuit 106, condition its receiver to detect R_f, $\overline{R_f}$ and SUV_d and transmit signal R_M for 384T followed by R_M' for 24T. The signal R_M shall begin on the boundary of a data frame.

9.9.2.1.2 The analogue modem shall then initialize the scrambler and differential encoder to zero and transmit SUV_u sequences with bit 32 clear and, after detecting R_f, R_f', condition its receiver to receive an SUV_d sequence and proceed according to 9.6.2.1.2. If signal R_d is detected, the modem shall proceed according to 9.8.2.2.1.

9.9.2.2 Responding to a fast parameter exchange

9.9.2.2.1 After detecting R_f, the analogue modem shall clamp circuit 104 to binary one and condition its receiver to detect the R_f-to-$\overline{R_f}$ transition.

9.9.2.2.2 After detecting the R_f-to-$\overline{R_f}$ transition, the analogue modem shall transmit signal R_M for 384T and then R_M' for 24T. The signal R_M shall begin on the boundary of a data frame.

9.9.2.2.3 The analogue modem shall then initialize the scrambler and differential encoder to zero and transmit SUV_u sequences with bit 32 clear and proceed according to 9.6.2.1.2.

9.10 Modem-on-hold

The MH sequences defined in 8.9.2 may be used to initiate modem-on-hold procedures when network interruptions occur due to call-waiting and related services. If an MH sequence is received, an appropriate MH sequence shall be transmitted in response.

9.10.1 Transmission of MH sequences

If Tone RT is transmitted before an MH sequence its duration shall be at least 20 ms if the tone was preceded by another MH sequence, or at least 50 ms otherwise. MH sequences shall be transmitted repeatedly, with the first 4 fill bits immediately following the last 4 fill bits of the preceding sequence. Each transmitted sequence shall be completed before transmitting other signals.

9.10.1.1 Initiating sequences

MH sequences MHreq, MHclrd and MHfrr may be transmitted to initiate a modem-on-hold transaction after circuit 107 has been asserted and either Tone RT is received or an MH response sequence is detected. MHnack may be transmitted to initiate a second transaction in response to MHreq. The initiating sequence shall be transmitted until the appropriate response is detected. If the appropriate response is not detected after 2 s plus a round-trip delay the modem shall complete the current sequence and either initiate a retrain or disconnect.

The beginning of a modem-on-hold transaction may be indistinguishable from the beginning of a retrain. Therefore, when a modem-on-hold transaction is initiated by transmitting Tone B, the responding modem may initiate a retrain by transmitting a Tone A phase reversal. In that case, the initiating modem will normally ignore the phase reversal and proceed with the modem-on-hold transaction. Correspondingly, the responding modem shall condition its receiver to detect both a Tone B phase reversal and an initiating MH sequence.

9.10.1.2 Response sequences

If one of the initiating sequences is detected the modem shall transmit the appropriate response shown in Table 34. The response sequence shall be transmitted repeatedly until either ANSam or silence is detected or the initiating sequence is not detected for 200 ms.

Table 34/V.92 – Initiating and response MH sequences

Initiating MH sequence	Response MH sequence
MHreq	MHack or MHnack
MHnack	MHcda or MHfrr
MHclrd	MHcda
MHfrr	ANSam

9.10.2 Modem-on-hold transactions

9.10.2.1 Modem-on-hold request

Sequence MHreq is transmitted to request the remote modem to enter an on-hold state (see Figures 20 to 22). If MHack is received, the modem may continue sending MHreq for a maximum of 30 s or send Tone RT or silence. If MHnack is received, the modem shall respond by transmitting either MHcda or MHfrr within 10 s.

If sequence MHreq is received, the modem shall transmit MHack to grant the on-hold request or MHnack to deny the request. If MHack is transmitted, the modem shall enter an on-hold state and when Tone RT is detected for 100 ms or silence is detected for 2 s, stop transmitting MHack and then transmit ANSam within 80 ms. Once in the on-hold state, a modem shall continue sending ANSam for time T1 and condition its receiver to detect signals from Phase 1 of the start-up procedure. If no such signals are detected after time T1 from the end of the first MHack, the modem shall exit the on-hold state and disconnect. If signal QC or signal CM are received, the modem shall proceed with Phase 1 of the start-up procedure, assuming the role of an answer modem and disregarding information received in previous phase 1 signals. If signal QC is detected with the U_{QTS} code set to 1111, cleardown from on-hold state, the modem shall disconnect. If a CM is detected with no PCM modem availability category and zeros for all modulation category modulation modes, the modem shall transmit a JM with no PCM modem availability category and zeros for all modulation category modulation modes. The modem shall then disconnect after reception of CJ.

If MHnack is transmitted in response to MHreq and MHcda is detected, the modem shall disconnect. If MHfrr is detected in response to MHnack, the modem shall transmit silence for up to 80 ms, transmit ANSam and proceed with Phase 1 of the start-up procedure, assuming the role of an answer modem and disregarding information received in previous phase 1 signals.

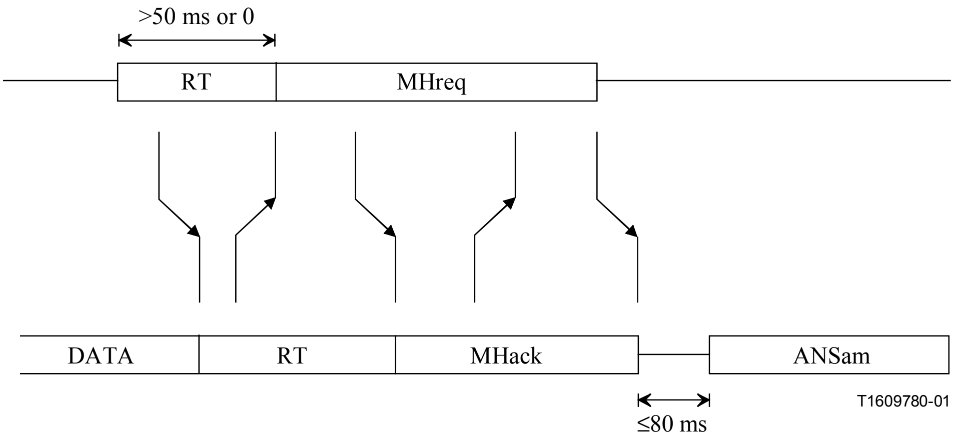


Figure 20/V.92 – Modem-on-hold request acknowledged

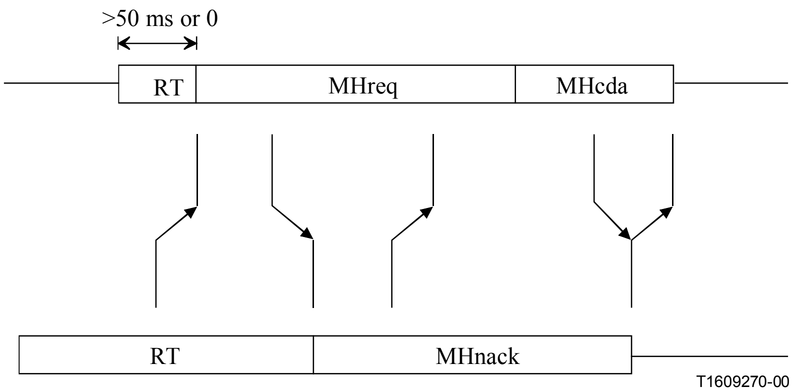


Figure 21/V.92 – Modem-on-hold request denied followed by cleardown request

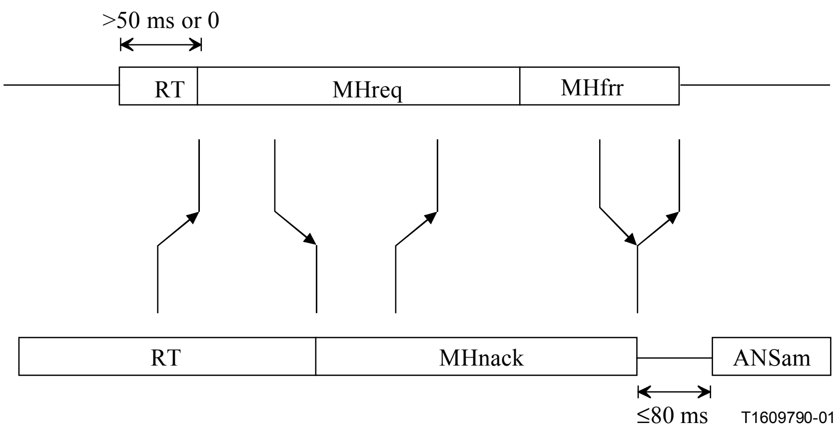


Figure 22/V.92 – Modem-on-hold request denied followed by fast reconnect request

9.10.2.2 Cleardown request

Sequence MHclrd is transmitted to request a cleardown (see Figure 23). The reason for the cleardown request shall be indicated in the information field of MHclrd as described in Table 32. When MHcda is received, the modem shall disconnect.

If MHclrd is received, the modem shall transmit MHcda. When either Tone RT or silence is detected or MHclrd is not detected for 200 ms, the modem shall disconnect.

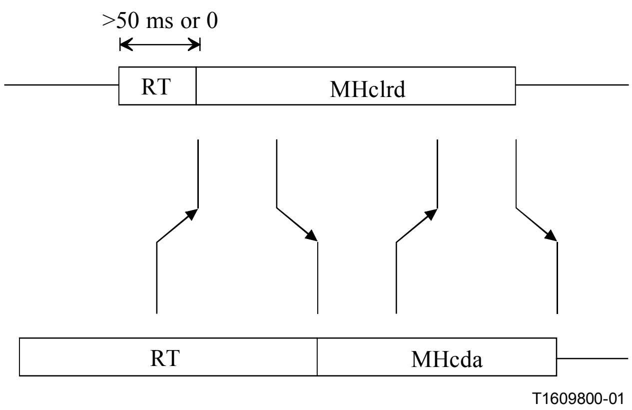


Figure 23/V.92 – Cleardown request

9.10.2.3 Fast reconnect request

Sequence MHfrr is transmitted to request a fast reconnect (see Figure 24). When ANSam has been detected for 1 s, the modem shall proceed according to Phase 1 of the start-up procedure.

If sequence MHfrr is detected, the modem shall transmit silence for up to 80 ms, transmit ANSam and proceed according to Phase 1 of the start-up procedure.

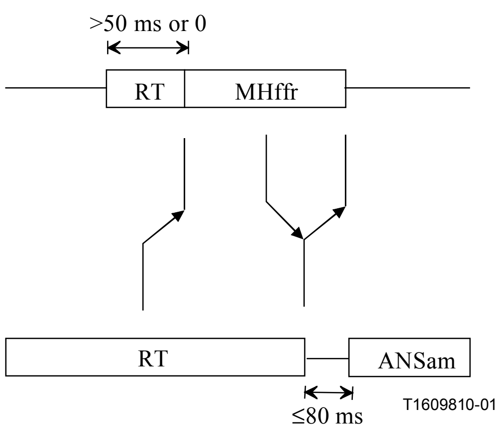


Figure 24/V.92 – Fast reconnect request

9.11 Cleardown

The cleardown procedure shall be used to terminate a connection. Cleardown is indicated by setting drn to 0 in either SUV_u by the analogue modem or SUV_d by the digital modem. This may be signalled at any time that a modem sends a rate sequence. To cleardown from data mode, a modem shall initiate either a rate renegotiation or a fast parameter exchange in order to send a rate sequence with drn = 0.

10 Testing facilities

Testing facilities as specified in other V-series modem Recommendations cannot be used for this Recommendation. Appropriate testing facilities are for further study.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series B	Means of expression: definitions, symbols, classification
Series C	General telecommunication statistics
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	TMN and network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile and leased circuits
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	**Data communication over the telephone network**
Series X	Data networks and open system communications
Series Y	Global information infrastructure and Internet protocol aspects
Series Z	Languages and general software aspects for telecommunication systems

Geneva, 2001

EXHIBIT H

ABSTRACT

The recent development of the V.34 modem standard permits full-duplex transmission at rates up to 33.6 kb/s in the ordinary general switched telephone network (GSTN). This article briefly describes the technologies that are used to make these dramatically increased bit rates possible. This new high-speed modem enables various new multimedia modem applications.

The V.34 High-Speed Modem Standard

G. David Forney, Jr., Les Brown, M. Vedat Eyuboglu, John L. Moran III, Motorola, Inc.

International Telecommunications Union — Telecommunications Standardization Sector (ITU-T) Recommendation V.34 [1] is a new standard for full-duplex data transmission over the general switched telephone network (GSTN) at bit rates up to 28.8 kb/s (recently extended to 33.6 kb/s). The standard was completed in the summer of 1994, and V.34-compliant modems were introduced by many vendors shortly thereafter. V.34 modems have quickly become low-priced consumer products, and are rapidly displacing 14.4 kb/s V.32bis [2] modems (1990) in popular applications such as remote access to corporate networks, on-line services, and the Internet.

The dramatically increased bit rates of V.34 modems, combined with recent advances in digital voice coding which provide near toll quality at rates of the order of 8 kb/s or less, and similar advances in very-low-bit-rate video coding which provide acceptable video quality for certain applications at rates below 20 kb/s, allow the simultaneous transmission of voice, data, and video over ordinary voice-grade GSTN lines. These advances have recently led to the development of new multimedia modem standards such as H.324 and V.70, described elsewhere in this issue.

This article provides a brief overview of the technology embodied in the V.34 standard. For more comprehensive treatments the reader may consult recent digital communications textbooks and *IEEE Transactions* papers, although often the best references are the actual standards contributions.

The V.34 standard incorporates proposals from many contributors, and represents the state of the art of digital transmission over bandlimited channels. Indeed, the technology in V.34 is superior to that proposed by any single company, and in that sense V.34 may be regarded as a triumph of the standards process.

FUNDAMENTAL PHILOSOPHY: ADAPTIVITY

One of the key factors contributing to the development of V.34 is the general upgrading of the GSTN throughout the world. On most connections today, the transmission medium is almost entirely digital, with a fairly short analog local loop connecting the subscriber at each end to this medium via a digital central office. The principal impairments encountered on most intracontinental connections are the quantization noise in the 8-bit μ-law or A-law pulse code modulation (PCM) conversion and the bandlimiting to about 3700 Hz by linear anti-aliasing and interpolation filters. The signal-to-noise ratio (SNR) on such a good digital channel is typically of the order of 34–38 dB.

On the other hand, the GSTN also incorporates many other types of carrier facilities, which can vary enormously in transmission characteristics. For example, on intercontinental connections the use of adaptive differential pulse code modulation (ADPCM) at 32 or 40 kb/s for improved voice transmission efficiency has become commonplace. ITU-T standards for ADPCM support about the same bandwidth as PCM but provide a reduced SNR: about 21 dB at 32 kb/s (G.721), or about 28 dB at 40 kb/s (G.726). Proprietary 32 kb/s ADPCM encoders/decoders (codecs) that support a reduced bandwidth of less than 3200 Hz at an SNR of about 28 dB are also in common use.

More generally, older analog carrier equipment typically has lower usable bandwidth and SNR than newer digital facilities. For example, the North American GSTN still incorporates some 40-year-old N-carrier systems that typically support less than 3000 Hz of bandwidth at an SNR of 24–28 dB, and are also susceptible to other impairments such as frequency offset, phase jitter, hits, and dropouts.

Consequently, the fundamental design philosophy of V.34 involves not only the latest modulation technology but also a much higher level of optional capabilities, intelligence, and adaptivity than in V.32bis or previous modem standards, in order to make the best use of these various types of connections. Both of these advances depend on the availability of inexpensive, programmable digital signal processing.

A V.34 transmitter and receiver jointly agree during initial startup on the bandwidth and bit rate to be used, as well as whether to use various modulation options that are specified in the V.34 standard, and the parameters of these options.

The result of this design philosophy is that a V.34 modem is a "best-effort" modem: it will transmit at as high a bit rate as possible, given the characteristics of the actual connection and the capabilities implemented in a particular modem. The percentage of lines over which a given bit rate such as 28.8 kb/s is actually achieved is then a statistical question, which we address at the end of this article.

Symbol rate			Low carrier			High carrier		
S	a	b	Frequency (Hz)	c	d	Frequency (Hz)	c	d
2400	1	1	1600	2	3	1800	3	4
2743	8	7	1646	3	5	1829	2	3
2800	7	6	1680	3	5	1867	2	3
3000	5	4	1800	3	5	2000	2	3
3200	4	3	1829	4	7	1920	3	5
3429	10	7	1959	4	7	1959	4	7

■ **Table 1.** *Symbol rates and carrier frequencies in V. 34.*

Adaptive Bandwidth

The single most significant factor contributing to the increased bit rates of V.34 is the use of the maximum possible bandwidth permitted by the channel.

Like all previous high-speed modem standards, V.34 uses quadrature amplitude modulation (QAM), in which the two components of a two-dimensional symbol are amplitude-modulated on in-phase and quadrature sinusoidal carriers at a common carrier frequency. The nominal Nyquist bandwidth is therefore equal to the symbol rate in Hertz, and the center of the band is at the carrier frequency.

In earlier modem standards such as V.32bis, the nominal bandwidth (symbol rate) was fixed at 2400 Hz with a fixed carrier frequency of 1800 Hz, resulting in a nominal transmission band of 600–3000 Hz. In V.34, however, the bandwidth and carrier frequency are both adaptive, with a maximum bandwidth of about 3429 Hz.

For example, at a rate of 8 b/s/Hz (8 bits per QAM symbol), a symbol rate of 2400 translates to a bit rate of 19,200 b/s, whereas a symbol rate of 3429 Hz translates to 27,429 b/s. Thus, at high bit rates there is a very large payoff from using the greatest possible bandwidth.

There are six symbol rates specified in V.34: 2400, 2743, 2800, 3000, 3200, and 3429 Hz. Of these, the three rates 2400, 3000, and 3200 are required in all V.34-compliant modems, while the remaining three are optional (although most modem manufacturers appear to have implemented 3429 Hz). These symbol rates are all of the form (a/b) x 2400 Hz, where a and b are small integers (see Table 1).

For each possible symbol rate S, one or two carrier frequencies of the form $(c/d)S$ are specified, in Table 1.

The symbol rate and carrier frequency are chosen during initial training. The transmitter sends a "line probing" sequence that generates a set of tones across the maximum possible band so that the signal-to-noise ratio can be measured as a function of frequency. The symbol rate and carrier frequency are then selected according to the results of this probing and the available symbol rates.

Adaptive Bit Rates

For consistency with earlier modem standards and to avoid excessive rate granularity, V.34 supports bit rates that are integer multiples of 2.4 kb/s, initially up to 28.8 kb/s (12 x 2400) and more recently up to 33.6 kb/s (14 x 2400).

Thus, the bit rate is usually not equal to an integer number of bits per symbol. (For example, 33.6 kb/s at a symbol rate of 3429 requires the transmission of 8.4 b/symbol.) A mapping technique involving a large "superframe" is used to accommodate all possible combinations of bit rate and symbol rate.

The bit rate is selected during training, according to the receiver's estimate of the maximum bit rate that can be supported at a reasonably low bit error probability such as 10^{-5}–10^{-6}. During data transmission, there are mechanisms for falling forward or back in bit rate according to the observed apparent error rate. The bit rates in the two directions of transmission may be different when both modems have the ability to support asymmetric bit rates.

Trellis Coding

One of the principal innovations in the V.32 9.6 kb/s modem standard (1984) was the use of trellis-coded modulation (TCM). At that time TCM was new, and a simple eight-state two-dimensional (2-D) trellis code was selected. This code, due to Wei [3], achieved an effective coding gain of about 3.6 dB.

Almost all of the trellis codes proposed for V.34 were four-dimensional (4-D) codes. 4-D codes have a smaller constellation expansion, which helps against certain non-Gaussian impairments, such as unequalized intersymbol interference (ISI). Also, certain 4-D codes have very good coding gains for their complexity. In particular, the 16-state 4-D trellis code of Wei [4] has an effective coding gain of about 4.2 dB, or 0.6 dB better than the V.32 code, with about the same decoding complexity. This code was used in all hardware prototypes for which performance results were submitted during standardization, and was eventually adopted for V.34.

Two additional, more powerful trellis codes were included in V.34 as further options: a 32-state 4-D code due to Williams [5], with an effective coding gain of about 4.5 dB, and a 64-state 4-D code, due again to Wei [6], with an effective coding gain of about 4.7 dB. The 32-state 4-D code involves a novel 4-D lattice partition, and is probably the nicest new code to come out of V.34 development. The 64-state 4-D code is a variant of Wei's original 64-state 4-D code [4], which was redesigned by Wei after Rossin *et al.* [7] discovered a flaw in the original code.

A V.34 transmitter is required to support all three encoders (since encoding is simple); however, a V.34 receiver may support whichever code(s) it likes.

In view of the relatively small returns in coding gain versus decoding complexity of more complex codes, it may be questioned why all three codes were included. The answer has to do partly with the relatively trivial cost in hardware of including multiple encoders, partly with the increased immunity of the more complex codes to impairments other than Gaussian noise, and partly with the dynamics of the standards process.

Shaping via Shell Mapping

Another advance since V.32 has been the recognition that there is a modest but not insignificant gain in forming signal constellations in high-dimensional spaces to minimize average signal power, quite independent of coding gain. This so-called shaping gain can never be greater than a factor of $\pi e/6$ (1.53 dB); however, it is not difficult to achieve shaping gains on the order of 1 dB.

Regulatory restrictions limit the average power of the signal transmitted on a telephone line. By minimizing average signal power, shaping maximizes the noise margin subject to these restrictions, at the cost of a larger QAM constellation and an increased peak-to-average ratio (PAR), which can lead to greater susceptibility to nonlinear impairments. The optimum shape in theory is a sphere in a high number of dimensions, but spherical constellations are difficult to implement and yield excessive constellation expansion and PAR.

After consideration of several shaping methods, a technique called shell mapping was eventually included in V.34. Shell mapping, which has been developed by many authors [8–12], is an algorithmic method of achieving near-spherical constellation shaping in a high number of dimensions with bounded QAM constellation expansion. V.34 specifies shell mapping in 16 dimensions with QAM constellation expansion limited to about 25 percent, which yields a shaping gain of about 0.8 dB. It also includes a shaping option with essentially no constellation expansion, which still achieves a shaping gain of about 0.2 dB.

The mapping algorithm also supports any integer number of bits per 16 dimensions (8 QAM symbols) up to a certain maximum, which in combination with appropriate framing and switching supports all the combinations of symbol rates and bit rates specified in V.34. V.34 uses nested signal constellations which can be generated easily as a subset of a single QAM superconstellation of 960 points, consisting of the 240 points shown in Fig. 1 and their rotations by 90°, 180°, and 270°. The recent increase of the maximum V.34 bit rate to 33.6 kb/s was accomplished simply by increasing the maximum constellation size to 1664 points.

Finally, V.34 also includes an option called "nonlinear encoding," which is designed to combat PCM quantization noise and nonlinear distortion [13]. These impairments typically cause larger perturbations in the higher-energy signal points, usually radially. If nonlinear encoding is enabled, a memoryless nonlinearity increases the distance between outer signal points at the cost of a slight decrease in distance between inner points.

Equalization and Precoding

All previous high-speed modems, such as V.32bis, use adaptive linear equalizers in the receiver to combat ISI. In these modems, the transmission band is confined to a "sweet spot" of 2400 Hz or less in which it is known a priori that channel attenuation will not be too severe.

In contrast, in V.34 every effort is made to make use of all available bandwidth, including frequencies near the band edges where there can be attenuation of as much as 10–20 dB. In such a situation it is well known that linear equalizers (which essentially invert the channel frequency response) cause significant "noise enhancement."

It is also well known that a decision-feedback equalizer (DFE) is well suited to such channels. However, it is not possible to combine coding with a DFE straightforwardly because decision feedback requires immediate decisions, whereas coding inherently involves decoding delay. The solution to this problem involves putting the feedback part of the DFE into the transmitter. Techniques of this type, which were devised many years ago for uncoded transmission by Tomlinson and Harashima [14–16], are called "equalization via precoding" or simply "precoding."

In the course of the V.34 development, a series of alternative forms of precoding were developed, each superior to its predecessor [17–22]. This development was an outstanding example of different contributors building on each others' work to develop a series of improvements that none would likely have arrived at individually.

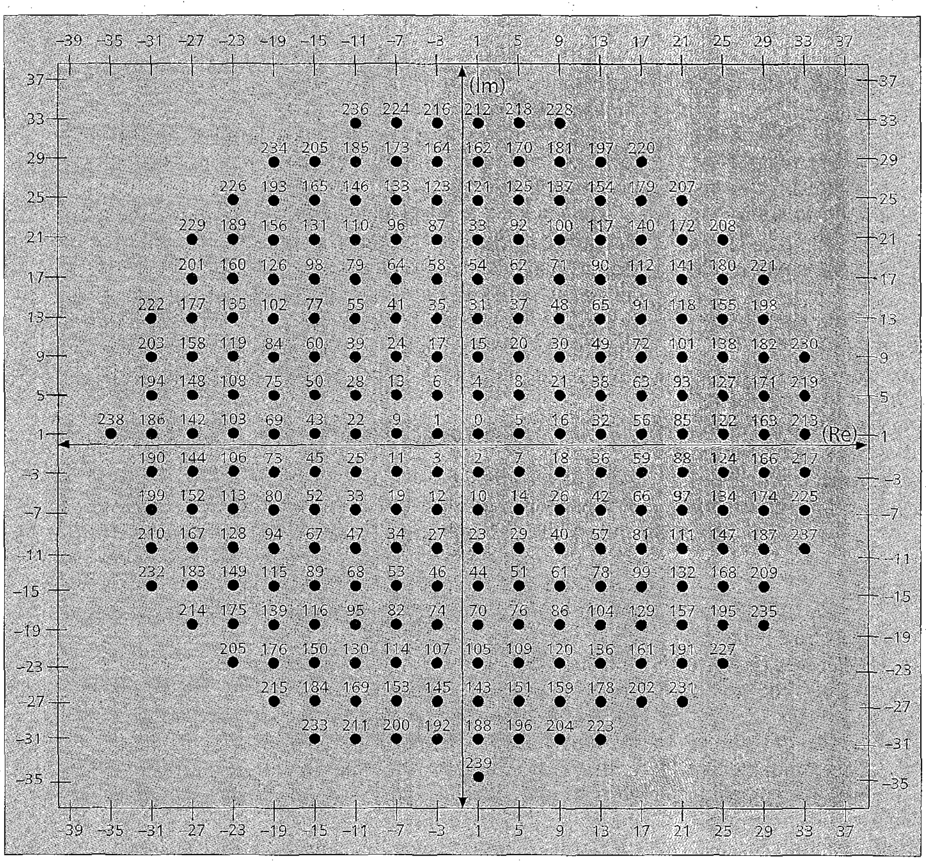
The V.34 standard provides for a simple three-tap precoding filter (representing the "feedback filter" in a DFE) whose coefficients are determined during initial training by the receiver and sent to the transmitter. The "feedforward filter" in the DFE is realized as an adaptive linear equalizer in the receiver and continues to adapt during data transmission.

To combat nonlinear impairments, V.34 also provides for optional transmitter pre-emphasis, which tends to reduce the signal level when the signal reaches the nonlinearity, and thereby to reduce the distortion seen by the receiver in situations where the nonlinearity is after the channel filter. V.34 also allows the receiver to request the transmitter to reduce the transmit power below its maximum allowed level to reduce the effect of nonlinearities.

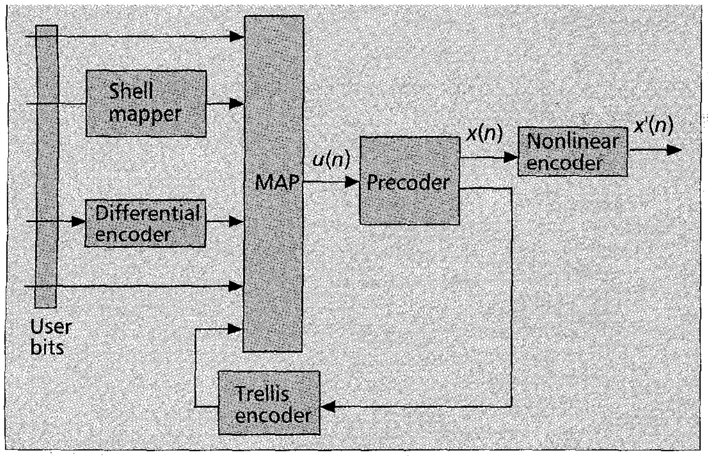
V.34 Transmitter

We now give an overview of the connections between these various elements in a V.34 transmitter, as illustrated in Fig. 2.

Given a particular bit rate and symbol rate (e.g., 28.8 kb/s at 3200 Hz), the transmitter must send a certain number of bits per QAM symbol (e.g., 9 in this case). If shaping is selected, the QAM constellation expansion is 75 percent over the constellation required to sup-



■ **Figure 1.** *V.34 quarter-superconstellation with 240 signal points. The full superconstellation is obtained by rotating these points by 0°, 90°, 180°, and 270°.*



■ **Figure 2.** *V.34 transmitter.*

port uncoded transmission, 50 percent due to trellis coding and 25 percent to shaping. For 9 b/symbol, for example, an 896-point signal constellation is required rather than the 512-point constellation required with no coding.

To implement shell mapping for this case, the signal constellation is partitioned into 14 equal-sized concentric rings of 64 points each. The encoder collects incoming user bits in frames of 72 bits over 8 symbol periods. Of these, 28 user bits are used by the shell mapper, which selects one of the 14 rings for each of the 8 QAM symbols in the frame; the rings are chosen so that the 16-dimensional signal point lies in a quasi-spherical 16-D region. The remaining 44 user bits, together with 4 coded bits generated by the trellis encoder, are then used 6 at a time to select one of the 64 transmitted signal points $u(n)$ in each selected ring. Some of the user bits are differentially encoded to ensure that the system is rotationally invariant.

The precoder and the trellis encoder are connected in a novel feedback arrangement, shown in Fig. 2. The current output of the trellis encoder determines the entire set of valid 4-D signal point pairs that may be selected by the precoder; the precoder selects one such 4-D pair, and the encoder then deduces the encoder state transition corresponding to that pair, thus determining its next state.

This arrangement minimizes the "dither" $d(n) = x(n) - u(n)$ that needs to be added to the signal point $u(n)$ by the precoder to generate the transmitted signal point $x(n)$. The dither sequence is selected so that after transmission through a channel with known linear distortion, the output sequence is equal to a valid trellis-coded sequence plus noise, and therefore can be decoded by a standard trellis decoder. The precoder minimizes the average transmitted power subject to this constraint, and ensures that the input data may be recovered from the decoded data in the receiver by a simple feedbackfree operation, so error propagation is limited.

After precoding, the sequence $x(n)$ may be optionally further modified by a nonlinear encoder to counter the effects of nonlinear distortion. The resulting sequence $x'(n)$ is typically filtered by a pulse-shaping filter, which, depending on the selections made by the receiver, may simply be a standard square-root-of-Nyquist filter with no spectral shaping, or a filter that provides pre-emphasis according to one of five spectral shapes defined in V.34. The output of the pulse-shaping filter is then modulated at the selected carrier frequency and power level for transmission over the telephone line.

Start-up and Operating Procedures

Recommendation V.34 specifies both duplex and half-duplex operating procedures. Duplex operation is for typical simultaneous two-way data applications, while half-duplex operation (one direction at a time) is primarily for facsimile. Duplex operating procedures include startup, retrain, rate renegotiation, and cleardown. Half-duplex operating procedures include both primary and control channel startup, resynchronization, and retrains.

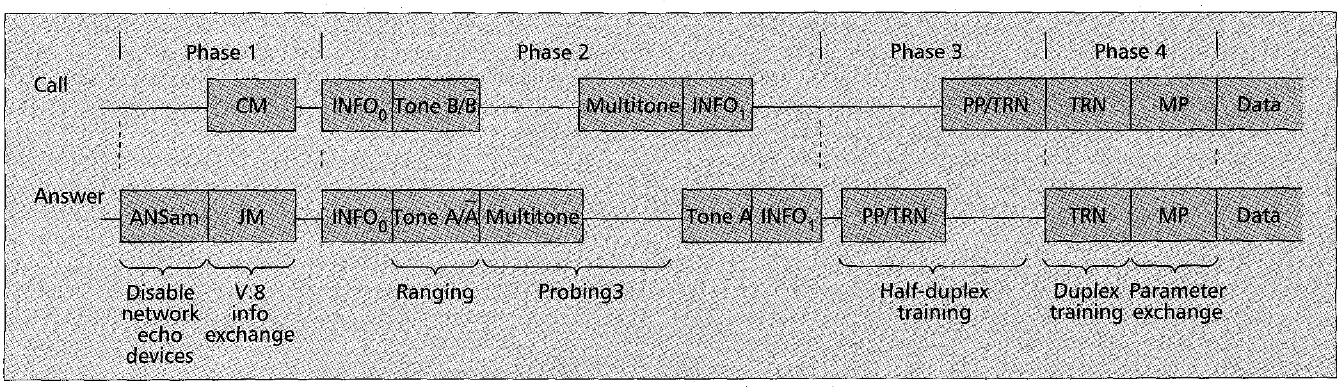
We shall discuss only duplex startup procedures in detail in this article. The half-duplex startup procedures are similar.

All operating procedures are designed to work well both under error-free conditions and in the presence of errors. The goal is to minimize startup time in the absence of errors, while providing slower but robust error recovery mechanisms to cope with errors.

V.34 duplex startup consists of four phases. Figure 3 is a simplified illustration of this sequence.

Phase 1, the network interaction phase, is based on Recommendation V.8 [23]. Its purposes are to disable network echo suppressors and cancellers, to provide for limited terminal selection between modem, fax, videotex, and text telephony, to provide for an improved "automoding" procedure over that in V.32bis (i.e., to determine the V-series modem recommendation used by the remote modem), and to allow network circuit multiplication equipment (CME) to switch in demodulation-remodulation (demod/remod) facilities; such facilities are used today for facsimile on international circuits in order to save bandwidth.

In order to allow for a V.8-capable calling modem to be able to differentiate between a V.8-capable answering modem and an older modem, while not causing existing equipment to malfunction, the normal 2100 Hz answer tone is modulated with a distinctive 15 Hz sine wave with a 20 percent modulation index.



■ **Figure 3.** *Simplified duplex startup sequence.*

Recommendation V.8bis, recently approved by the ITU, improves over V.8, particularly in multimedia applications, by allowing a call to start in the regular voice mode and then smoothly transition into a voice-and-data or video mode.

Phase 2, the ranging and probing phase, consists of an initial information exchange ($INFO_0$), ranging and probing sequences, and a second information exchange ($INFO_1$). The information exchanges use 600 bit/s frequency-division multiplexed (FDM) differential phase shift keying (DPSK) modulation at carrier frequencies of 1200 Hz and 2400 Hz.

$INFO_0$ is used to convey capability information such as which optional symbol rates are supported, regulatory bandwidth restrictions, and maximum allowed asymmetry of the transmit and receive symbol rates.

Ranging uses phase reversals during tone transmission to determine the round-trip delay of the connection for proper placement of the modem's far-end echo canceller taps.

Probing is used to determine the channel characteristics. The probing signal consists of a set of tones of equal amplitude spaced 150 Hz apart at frequencies from 150 Hz to 3750 Hz. This signal may be used to measure the amount of amplitude distortion across the band, the SNR across the band, and the frequency offset for a given channel. Tones at 900, 1200, 1800, and 2400 Hz are omitted to allow for the measurement of the level of intermodulation distortion products. The probing signal is transmitted first at 6 dB above the nominal power level and then at the nominal power level. This permits the measurement of overall nonlinearity, which in turn can be used to determine the amount of power reduction that a modem requests of a far-end transmitter.

$INFO_1$ is used to convey the results of probing measurements in terms of projected maximum bit rate, and to select the symbol rate, carrier frequency, pre-emphasis filter, and a range of power reduction to be used by each modem. $INFO_1$ also indicates the duration of the optional Phase 3 echo-canceller training sequence.

Phase 3, the equalizer and echo-canceller half-duplex training phase, consists of a series of signals transmitted first by the answering modem and then by the calling modem. Each series consists of an optional manufacturer-defined echo-canceller training signal, a short periodic sequence for fast equalizer training, a sequence of scrambled binary 1s for fine tuning of the equalizer and echo canceller, and a repeating 16-bit scrambled sequence indicating the constellation size that will be used during Phase 4 of the startup procedure. These scrambled sequences are transmitted using a four-point constellation. The repeating 16-bit scrambled sequence continues until interrupted by reception of a tone from the remote modem indicating that its receiver has completed equalizer training.

Phase 4, the final duplex training phase, consists of a sequence of scrambled binary 1s and a modulation parameter exchange, following which the selected modulation features and options are enabled. The sequence of scrambled binary 1s uses either a 4- or 16-point QAM constellation and is used to train precoder coefficients and fine-tune the equalizer and echo canceller. If a 16-point constellation is used, measurements of nonlinear distortion may also be made, which may be used to decide whether or not to invoke the nonlinear encoding option.

The modulation parameter exchange is used to indicate the final modem bit rates (based on duplex performance measurements), exchange the precoder coefficients to be used by each modem, select the trellis encoder and the degree of nonlinear encoding and shaping to be used by each modem, and indicate the capability to use a 200 b/s auxiliary channel. The modulation parameter exchange is terminated by a well-defined marker, after which all of the selected modulation features are immediately enabled and the transmission of user data commences.

The total startup time for duplex operation is nominally about 10 s, but may vary from 4 s plus 9 round-trip delays to 13 s plus 12 round-trip delays, depending on implementation.

Either modem may initiate a retrain during duplex data mode. There are two types : long retrain, starting at Phase 2 of duplex startup, and short retrain/rate renegotiation, starting at the beginning of Phase 4 of duplex startup. The short retrain is typically used to change bit rates (up or down) or resynchronize the receiver without performing a full retrain. The long retrain is typically used when a short retrain has failed, or a modem wishes to change its symbol rate or carrier frequency, or needs to retrain its echo canceller.

Performance and Testing

The technologies used in V.34 were selected on the basis of their ability to expand the percentage of connections over which high bit rates could be achieved on the actual GSTN.

It was understood that traditional measurements of bit error probability as a function of SNR on a linear Gaussian channel could not be the whole story of predicting actual GSTN performance. Therefore, a statistical model of actual transmission facilities and loops was developed to evaluate V.34 technologies [24]. This novel approach was based in large part on available GSTN survey data in the United States for the likelihood of occurrence of certain impairments as a function of transmission facility type [25] and the likelihood of occurrence of local loops [26]. This 1984 data base was updated using 1989 Federal Communications Commission (FCC) petition filings [27] detailing the percentages of types of switches installed in the U.S. GSTN and projections of future installations up to 1994.

The performance evaluation criterion was reduced to a single percentage score representing the network model coverage (NMC). This criterion has proved to be a reasonably accurate predictor of how a given V.34 modem will operate in the real GSTN, and has been widely adopted by laboratories that perform V.34 modem evaluations. It has also been embodied in the U.S. standard Telecommunications Industry Association (TIA) TSB-37A in the United States and the international ITU-T Recommendation V.56bis [28].

The V.56bis test suite is a network model comprising 168 connection types in total, based on 7 local loop combinations and 24 end-office-to-end-office combinations. All combinations are weighted based on their likelihood of occurrence (LOO) in the network. The NMC is the total LOO for which a specified block error rate (BLER) can be achieved. The behavior of NMC as a function of BLER can be used as a more realistic replacement for the traditional waterfall curves of BLER versus SNR for ideal Gaussian channels, although of course the amount of testing required to develop these numbers is much greater.

In practice, different V.34 implementations achieve different bit rates on the same connection, depending on which options are implemented and how they are implemented. It thus becomes rather difficult to give a precise answer to the question, "How fast do V.34 modems really go?" Experience indicates a rate of 28.8 kb/s can be achieved over the majority of lines in North America, Europe, and Japan, and 24 kb/s over practically all lines except for intercontinental links with ADPCM, where 16.8 or 19.2 kb/s is often the practical limit.

What's Next for Modems?

Some say that "V.fast = V.last" — V.34 is the ultimate modem standard. History tells us this is not likely to be the case. Some modem manufacturers have recently announced plans to develop super-high-speed modems that can operate at rates well above 33.6 kb/s. The technical concept behind these new modems is described by Humblet and Troulis in this issue [29]. With the growing popularity of multimedia applications and the Internet, modem engineers will continue to seek ways to extend the life of voiceband modems.

A project to develop an enhanced version of V.34 is now underway in the ITU-T. This work could lead to faster startup and the possibility of seamless rate switching, which are important enhancements for the multimedia applications discussed in this issue. Other features will surely be added over time.

Acknowledgments

The V.34 standard was created through the efforts of a great many people in many companies over several years, including a number of our colleagues in Motorola, as well as other participants in the TIA 30.1 and ITU-T Study Group 14 standards meetings. We cannot possibly acknowledge all these contributors individually; we can only repeat that we regard V.34 as a major triumph of the standards process. We would also like to acknowledge the helpful suggestions of the reviewers.

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Biographies

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Les Brown was born in Vancouver, Canada, on December 8, 1949. He received the B.A.Sc. degree in electrical engineering from the University of Toronto in 1972, and the MASc. degree in electrical engineering, specializing in active filter design, from the University of Toronto in 1977. In 1981 he joined ESE Ltd., then a subsidiary of Codex Corporation (now Motorola ISG), and currently holds the position of principal staff engineer. Mr. Brown has been involved in all facets of modem development over the years. He is also the Motorola ISG representative in modem-related standards committees, holding several positions of leadership, including the chairmanship of TIA TR-30.1 and several rapporteurships in ITU-T SG14.

Vedat Eyuboglu [F] received his B.S. degree from Bogazici University, Istanbul, Turkey, and M.S. and Ph.D. degrees from Rensselaer Polytechnic Institute in Troy, New York, in 1980 and 1984, respectively. He is a vice president at Motorola's Information Systems Group and is the manager of the Signal Processing R&AD Department in Mansfield, Mass. His group is involved in research and development on high-speed modems, multimedia and broadband access technologies, in particular for Hybrid Fiber/Coax Networks. Dr. Eyuboglu was a key contributor to the development of the V.34 high-speed modem standard and the H.223 multimedia multiplexing protocol of H.324. Dr. Eyuboglu is a Dan Noble Fellow and Distinguished Innovator of Motorola. He holds over 25 issued/pending patents.

Jack L. Moran is a principal staff engineer at Motorola Information Systems Group in Mansfield, Massachusetts. He has worked as an electrical engineer in the communications industry for over 19 years. He has been with Motorola for 15 years where he worked primarily on analog hardware design. Over the past 12 years he has conducted numerous surveys to characterize the public telecommunications network throughout the world and has applied this knowledge to develop network models to evaluate modem performance. Mr. Moran has been an active participant in IEEE Committee P 743, TIA TR-30, T1A1, and ITU-T SG 14. He was Editor and chief sponsor for TIA Telecommunications System Bulletin TSB-37-A and ITU-T Recommendation V.56 bis. More recently, Mr. Moran has been involved in the design and testing of cable modems. He holds several patents in the field of data communications.

EXHIBIT I

Transactions Papers

V.92: The Last Dial-Up Modem?

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***Abstract*—Ever since the first dial-up modems appeared in the 1960s, their obsolescence has been repeatedly predicted. However, contrary to such predictions, dial-up modems thrived in the 1980s and 1990s as a result of the slow rollout of residential digital services and the unprecedented growth of internet and remote access. Since the first 300 b/s dial-up modem standard (V.21), modem speeds have increased steadily. Most recently, International Telecommunications Union (ITU) Recommendation V.90 (1998) takes advantage of the direct digital-network connection of an internet service provider (ISP) remote-access server to achieve speeds of more than 50 kb/s downstream (from ISP to a user). However, for upstream transmission (from a user to ISP), V.90 employs the older V.34 modulation (1994), which typically delivers on the order of 30 kb/s. A new ITU modem standard called V.92 increases upstream rates to above 40 kb/s, again by taking advantage of pulse code modulation connections. In this paper, we present the transmission scheme that has been adopted for V.92. It involves a generalization of Tomlinson–Harashima precoding. We predict that V.92 will be the last dial-up modem standard. However, we have to wonder whether we might be falling into the same trap into which many others have fallen in the past. The future will be the judge!**

***Index Terms*—Dial-up modem, pulse code modulation (PCM) modem, Tomlinson–Harashima precoding, V.90, V.92, 56k modem.**

I. Introduction

FIG. 1(a) gives a network-oriented view of a conventional voiceband modem connection. Conventional modems, including V.34 [11], do not take account of analog-to-digital (A/D) and digital-to-analog (D/A) conversion processes in the telephone network [1]. Therefore, their performance is limited by the quantization noise that is introduced by pulse code modulation (PCM).

If the quantization noise is treated as additive white Gaussian noise (AWGN), then the capacity of the telephone network for conventional voiceband modems can be calculated from the Shannon capacity formula [3]

$$C = W \log_2(1 + \mathrm{SNR}) \tag{1}$$

where W is the channel bandwidth and SNR is the signal-to-noise ratio. Since W is about 3–3.7 kHz and the SNR due to quantization noise is about 36 dB, the capacity C does not exceed about 36–44 kb/s, even in the absence of thermal noise and of other external disturbances.

PCM modems [1] allow data transmission at over 50 kb/s downstream, e.g., from a service provider digitally connected to the public switched telephone network (PSTN) to a user who is connected through an ordinary telephone line. Fig. 1(b) shows such a connection through the PSTN for a PCM modem.

The International Telecommunications Union Telecommunication Standardization Sector (ITU-T) completed PCM modem Recommendation V.90 in 1998 [2]. V.90 takes into account the D/A converter in the downstream, and thereby eliminates quantization noise for downstream transmission. As described in [1], V.90 uses a subset of the A/μ-law quantization levels as a pulse amplitude modulation (PAM) signal constellation, at a symbol rate of 8000 symbols/s. In contrast to conventional PAM systems, in PCM modems, signal point selection and transmitter pulse shaping occur inside the network, in a PCM D/A converter. This restricts the PAM signal constellation to a subset of the A/μ-law quantizer levels. Therefore, the V.90 downstream rate is limited to 64 kb/s (8 b/symbol, 8000 symbols/s). In reality, the rate is limited to less than 56 kb/s, due to a Federal Communications Commission (FCC)-mandated power constraint [1], digital impairments such as robbed-bit signalling (RBS), and channel noise.

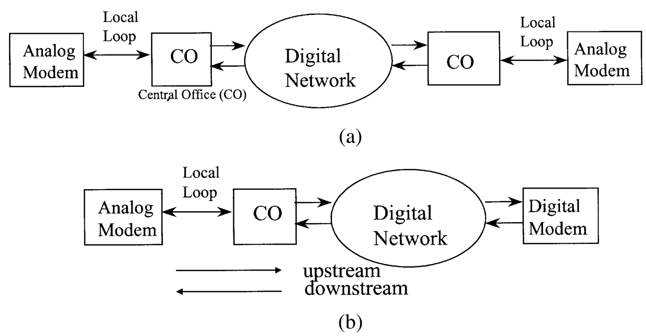

Fig. 1. Modem connections through a public switched telephone network (PSTN). (a) Analog end-to-end connection. (b) PCM modem connection.

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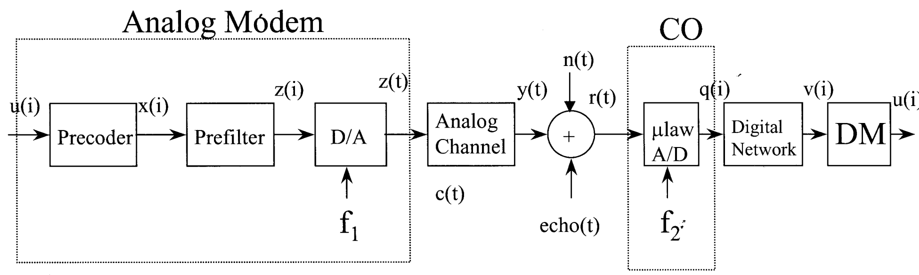

Fig. 2. Block diagram for upstream.

For upstream transmission, V.90 uses the same modulation as V.34, and therefore can achieve a maximum data transmission rate of only up to 33.6 kb/s. To achieve higher rates, the A/D quantizer in the central office (CO) must be taken into account. To avoid quantization distortion in the upstream PCM, the analog loop should be equalized at the transmitting modem, and transmit timing should be precisely matched to the sampling timing of the A/D converter. Such timing can be acquired from the timing of the D/A on the downstream link.

Ayanoglu *et al.* made an earlier proposal for a new transmission scheme for PCM upstream [4], [5]. In this proposal, the sampling rate is less than 8 kHz, and multiple-input/multiple-output (MIMO) system theory is used for preequalization.

In this paper, we present the transmission scheme to achieve data rates higher than 33.6 kb/s for PCM upstream that was adopted in June, 2000 by the ITU-T in the next dial-up modem Recommendation V.92 [21]. This scheme employs a new precoding scheme that is a generalization of Tomlinson–Harashima precoding (THP) [6]. This scheme also includes a design for optimal constellations for PCM upstream transmission.

We introduce generalized THP in Section II. Optimal constellation design is explained in Section III. Section IV discusses the trellis coding scheme used in V.92. Section V discusses similarities and differences between our proposed transmission scheme and that of [5].

II. New Transmission Scheme

Fig. 2 shows the block diagram of our PCM upstream transmission system. In our system, an "analog PCM modem" is connected to a CO over a local analog loop. Channel noise and echo from downstream transmission are added to the received signal before it is quantized by the A/μ-law quantizer at a sampling frequency of $f_2 = 8$ kHz. The quantized octets [16], denoted by $q(i)$, are transmitted over the digital network, where they may be affected by various digital impairments such as RBS [16], and they are processed by the "digital PCM modem" directly connected to the PCM network.

Before data can be transmitted upstream, the clock (f_1) in the analog PCM modem must be synchronized to the clock (f_2) of the A/D. This can be achieved by learning the clock from the downstream PCM signal, and synchronizing the clocks using techniques such as those described in [7]. In this paper, we assume perfect clock synchronization. Once the clocks are synchronized, i.e., $f_1 = f_2$,[1] the PCM upstream block diagram can be represented by an equivalent discrete-time block diagram, as shown in Fig. 3. In Fig. 3, i is the time index for 8-kHz samples.

[1]Note that f_1 and f_2 do not have to be the same, as long as they are synchronized. For example, the block diagram when $f_1 = 2f_2$ is given in Fig. 4. In this paper, we assume $f_1 = f_2$ to simplify explanations.

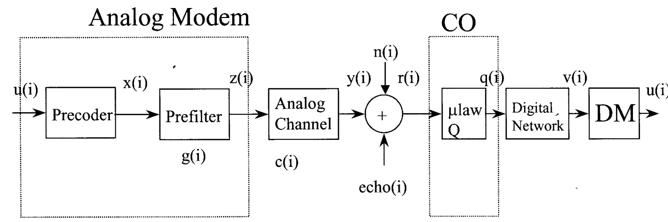

Fig. 3. When $f_1 = f_2$. The index i is the time index for 8-kHz samples.

As we have said, the signal at the A/D converter includes echo from the downstream transmission in a full-duplex system. Although this echo can be estimated in the digital modem, it prevents us from ensuring that the received signal at the A/D will fall on a quantization level, even in absence of noise. Thus, in contrast to the downstream case, quantization noise cannot be avoided in the upstream direction.

The analog channel should be equalized at the transmitter, since equalization at the receiver is not compatible with computation of proper likelihoods (see Section III). Since the analog channel has a spectral null at DC [1], preequalization by a linear filter is not possible. Therefore, we use a preequalization system based on a precoder and a prefilter, as shown in Fig. 3.

The prefilter $g(i)$ is designed so that the overall response $p(i) = g(i)^*c(i)$ is causal and monic. The precoder acts as a decision-feedback circuit to remove the remaining causal interference. The precoder and prefilter are designed to transmit the signal $z(i)$ over the analog channel, such that predetermined constellation points $y(i)$ (see Section III) corresponding to digital data symbols $u(i)$ are produced at the input of the A/μ-law quantizer, if there is no noise and no echo. In the presence of noise and echo, the input of the A/μ-law quantizer will be $y(i) + n(i) + \text{echo}(i)$. Here, $\text{echo}(i)$ denotes the echo, while the noise term $n(i)$ includes additive channel noise, intersymbol interference (ISI) from imperfect equalization, and noise from imperfect echo estimation.

To explain the operation of the precoder and prefilter, Fig. 3 is redrawn in Fig. 5 on the assumption that there is no echo, no quantizer, and no digital network. We assume that the analog channel $c(i)$ has been accurately estimated during training. The prefilter $g(i)$ and the target causal, monic response $p(i)$ (where $p(0) = 1$) can be derived by minimizing the cost function

$$\zeta = \|g(i)^*c(i) - p(i)\|^2 + \alpha \|g(i)\|^2 . \qquad (2)$$

The first term ensures small ISI, while the second term ensures small transmit power through the Lagrange multiplier α.

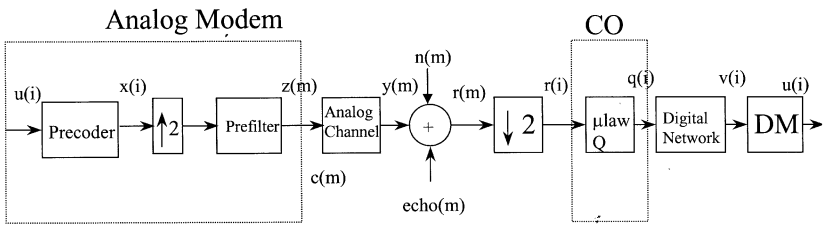

Fig. 4. When $f_1 = 2^* f_2$. Here, m and i are the time indexes for 16-kHz and 8-kHz samples, respectively.

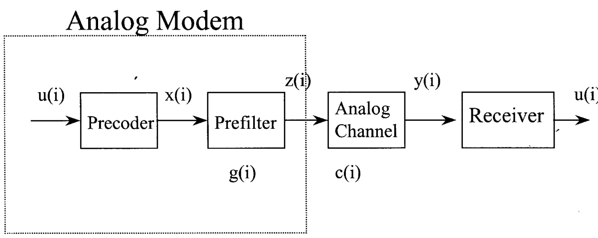

Fig. 5. Precoding scheme used for upstream. To simplify the explanation, we assume no echo, no quantizer, and no digital network.

The larger α, the lower will be the transmit power, but the larger will be the ISI.

Minimization of the cost function ζ is similar to determining the optimal feedforward and feedback filters for a decision-feedback equalizer (DFE). A computationally efficient algorithm can be found in [8]. Note that in the limit of infinitely long filters, with a zero-forcing design, $g(i)$ will simply be an all-pass filter. We observe in practice that it is usually almost all pass. The initially determined $p(i)$ and $g(i)$ can be used for as long as the analog channel $c(i)$ is time invariant. In practice, the analog channel is almost time invariant, and a fixed $p(i)$ and $g(i)$ can maintain initial performance for several hours.

Assuming that $p(i) = g(i)^* c(i)$, the following relationship holds:

$$y(i) = p(i)^* x(i). \tag{3}$$

Since $p(0)$ is designed to be 1 and $p(i) = 0$ when $n < 0$ or $n > N_p$, (3) can be rewritten as

$$x(i) = y(i) - \sum_{k=1}^{N_p} p(k)x(i-k). \tag{4}$$

Since $p(i)$ and the past values $x(n-i), i = 1, 2, \ldots, N_p$, are known, the value of $x(i)$ needed to produce a given $y(i)$ at the output of the channel can be easily derived from (4).

The system (4) is unstable. However, we have some freedom in choosing $y(i)$ as a function of the data symbol $u(i)$ to send information over the channel. The given constellation points[2] for $y(i)$ are grouped into equivalence classes labeled by $u(i)$, and, given $u(i)$, one of the points in the corresponding equivalence class will be used as $y(i)$. The signal point $x(i)$ can then be computed according to (4). As the signal sequence $x(i)$ is almost white and $g(i)$ is almost all pass, choosing the point in the equivalence class to minimize $x(i)$ also tends to minimize the transmitted power $||z(i)||^2$ at the prefilter output.[3]

An equivalence class is a set of one or more constellation points that represent the same data symbol $u(i)$. Let the N constellation points be denoted by a_j, $-(N)/(2) \le j < (N)/(2)$, where the indexes[4] are in the same order as the levels. Thus, negative points have negative indexes, and positive points have nonnegative indexes. Let the data $u(i)$ have M possible values, say $0 \le u \le M-1$. The equivalence class $E(u)$ corresponding to u is then defined as the set of all constellation points that have indexes congruent to u modulo M; i.e., $E(u) = \{a_j | j = u + zM, z \text{ an integer}\}$.

For example, if $N = 10$ and $M = 4$, then the four equivalence classes are $E(0) = \{a_{-4}, a_0, a_4\}$, $E(1) = \{a_{-3}, a_1\}$, $E(2) = \{a_{-2}, a_2\}$, and $E(3) = \{a_{-5}, a_{-1^-}, a_3\}$, as shown in Fig. 6.

There is a tradeoff between data rate, i.e., the number of equivalence classes, and transmit power. As data rate increases, i.e., the number of equivalence classes increases, the number of points in an equivalence class decreases and the distance between them increases. Thus, the smallest corresponding $x(i)$ and the transmit power get bigger.

The constellation for $y(i)$ will be called the *base constellation*.[5] As shown in the next section, the base constellation can be designed to satisfy a certain target decoder error rate for given echo and noise characteristics on the line. From this base constellation, the equivalence class should be chosen to satisfy the transmit power constraint. This will give the supportable bit rate for a given transmit power constraint and line conditions.

We note at this point that although we have defined equivalence classes for one-dimensional (1-D) constellations, equivalence classes could alternatively be defined for multidimensional constellations, or even for trellis codes, using techniques similar to those in [14] and [15]. This could give us a "shaping gain" which would help to reduce the transmit power, although at the expense of increased computational complexity. For example, Fig. 7 gives an equivalence class defined for a two-dimensional (2-D) constellation, where the number of points in the first and second dimension is assumed to be 12. The first data symbol, $u(2m)$, is assumed to have four values, and the second data symbol, $u(2m+1)$, six values. The equivalence class for input data symbols $u(2m) = i$ and $u(2m+1) = j$ is denoted by the index pair ij.

[2]The constellation design for $y(i)$ will be covered in Section III. In this section, we assume the constellation points for $y(i)$ are given.

[3]The selection could also look ahead to minimize $||x(i)||$ or even $||z(i)||$.

[4]Index j is not a time index.

[5]Note that $y(i)$ are the actual numerical values of the constellation points instead of the index.

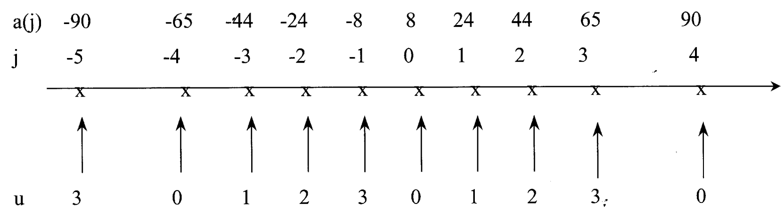

Fig. 6. How to choose equivalence classes within constellations. (Here, u can be 0, 1, 2, or 3, and there are 10 constellation points.

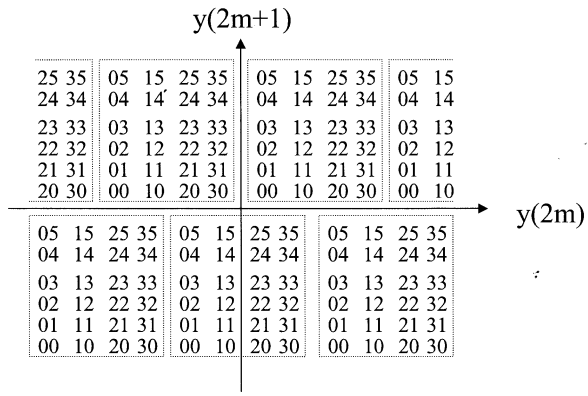

Fig. 7. Two-dimensional equivalence classes, with $u(2m) = 0, 1, 2, 3$, and $u(2m+l) = 0, 1, 2, 3, 4, 5$.

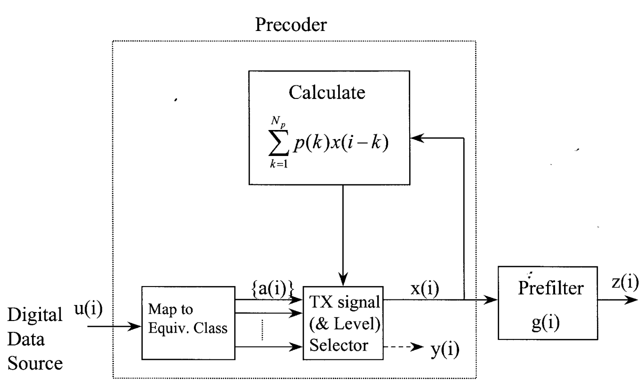

Fig. 8. Block diagram of precoder and prefilter.

In the rest of this paper, we assume 1-D equivalence classes, as are used in V.92.

THP [6] can be seen to be a special case of the proposed 1-D equivalence class definition, in which the base constellation is a uniform PAM constellation with an infinite number of points. Therefore, our precoding scheme will be called generalized THP (GTHP).

Fig. 8 summarizes the operation of the precoder and the prefilter. Given digital data $u(i)$, the equivalence class of $u(i)$ is passed to the transmit signal point selector. One of the points in this equivalence class is chosen as $y(i)$, and then $x(i)$ is calculated from (4) and passed through a prefilter prior to transmission over the channel. The signal points $y(i)$ are chosen to minimize the energy of $x(i)$.

III. Constellation Design

The explanation of the precoder and prefilter in the previous section ignored echo and quantization. In this case, $y(i)$ is affected only by additive noise, and therefore, the receiver can decode the data sequence $y(i)$ straightforwardly, using a trellis decoder in the presence of channel coding, or a symbol-by-symbol slicer in the absence of channel coding (see Fig. 9). Then $u(i)$ can be recovered from $y(i)$ based on the equivalence class definition.

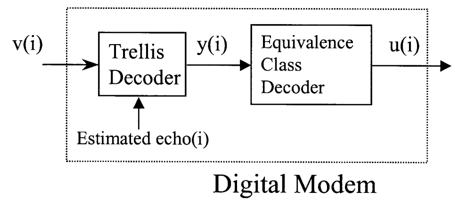

Fig. 9. Receiver (digital modem) in the presence of channel coding.

In this section, we first show how the receiver decodes the data sequence in the presence of noise, echo, and quantization. With this understanding, we will design an optimal base constellation for $y(i)$.

Our constellation design method is not restricted to the precoding scheme proposed here, but may be used with various other precoding schemes, including that of [5].

Other papers, including [10], assume that the constellation should be a subset of the A/μ-law quantization levels. However, it will shortly be evident that this constraint should be relaxed to achieve an optimal constellation.

Fig. 3 shows the block diagram of PCM upstream in the presence of echo, quantization, and digital network impairments. The analog channel output $y(i)$ is affected by noise and echo before μ-law quantization.

The digital network may distort the μ-law quantizer output $q(i)$ into $v(i)$ through digital impairments such as RBS and digital loss [16]. We will describe the design of optimal constellations assuming that there are no digital impairments in the digital network, i.e., $v(i) = q(i)$. These results can be easily extended to the case when $v(i)$ is not equal to $q(i)$ by defining a new quantizer that combines the μ-law quantizer and the digital impairments introduced by the digital network. Digital impairments may be identified by the technique given in [12].

The optimal constellation depends on the decoding scheme utilized by the digital modem. It will first be shown how to design the constellation assuming symbol-by-symbol decoding. Then the constellation design will be generalized to the case where there is trellis coding, and the decoder employs a sequence-based decoding scheme, such as the Viterbi decoding algorithm [6]. Our constellations will be designed to achieve a predetermined target error probability.

When the digital modem receives $v(i)$, given an estimate of echo(i), the digital modem can decode which $y(i)$ has been

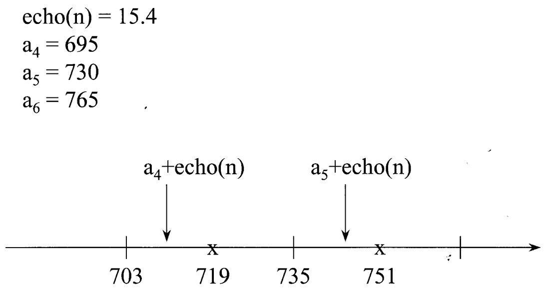

Fig. 10. Symbol-by-symbol decoding: Small-echo example.

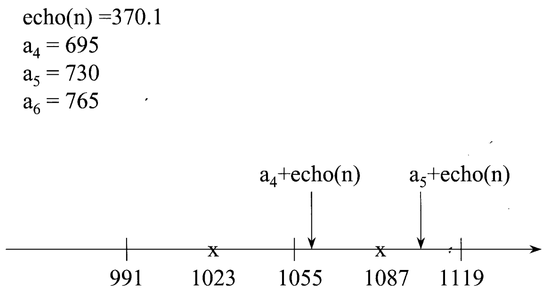

Fig. 11. Symbol-by-symbol decoding: Large-echo example.

transmitted by finding the most probable a, i.e., the a that maximizes

$$\operatorname*{Max}_{a} \Pr\left(v(n)|a, \mathrm{echo}(n)\right). \tag{7}$$

If the noise $n(i)$ is Gaussian with variance σ_{n}^2, then this probability is given by

$$Q\left(\frac{(v^l(i) - a - \mathrm{echo}(i))}{\sigma_n}\right) - Q\left(\frac{(v^u(i) - a - \mathrm{echo}(i))}{\sigma_n}\right) \tag{8}$$

where $v^l(i)$ and $v^u(i)$ are, respectively, the lower and upper limits of the quantization interval associated with $v(i)$, and $Q(x)$ is the Gaussian probability-of-error function. Note that the noise standard deviation is often dominated by $\mathrm{echo}(i)$.

The decoding process may be better understood by observing the symbol-by-symbol decoding example depicted in Fig. 10. In this figure, the "x" marks on the axis represent μ-law quantizer levels, and the "|" marks represent μ-law threshold levels. As specified in G.711 [16], there are 255 μ-law quantized levels with predefined thresholds. Of course, Fig. 10 depicts only a small number of all of the possible levels.

In this example, it is assumed that a certain base constellation has points $y_4 = 695$ and $y_5 = 730$, and that $\mathrm{echo}(i) = 15.4$. If the digital modem receives $v(i) = 751$,[6] then it will determine that a_5 has been transmitted, since, in the presence of noise, a_5 has the highest probability of having been the transmitted constellation point, given $\mathrm{echo}(i)$, because it is the only point falling between the thresholds surrounding the μ-law level $v(i) = 751$.

Another example with the same constellation points is shown in Fig. 11. In this example, however, $\mathrm{echo}(i) = 370.1$. In this case, for either transmitted constellation point, a_4 or a_5, the digital modem will receive $v(i) = 1087$. As a result, the digital

[6]To be precise, $v(i)$ is a μ-law code which ranges from -127 to 128 [16]. However, in this paper, we use $v(i)$ to represent both the μ-law code and its decoder amplitude (which ranges from -8031 to 8031 [16]), since it will be evident from the context which it represents.

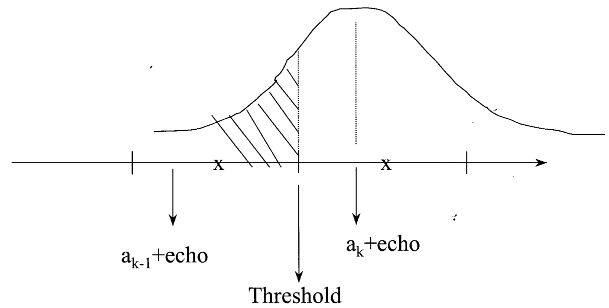

Fig. 12. Calculation of probability of error.

modem will have difficulty distinguishing between a_4 and a_5, and therefore, these points will have a high error probability. The constellation should be designed so that this kind of error happens rarely enough to achieve some target symbol-error probability (SEP) (e.g., $P_e = 10^{-6}$). This could be achieved by increasing the distance between the constellation points; however, this will reduce the number of points that can be used in the constellation, which will reduce the data rate for fixed transmission power.

As shown by these examples, the constellation design depends heavily on the echo characteristics. As will be evident from the following algorithm, different constellations are optimal for different echo and noise characteristics.

We now give an algorithm to design the base constellation to achieve a certain target error probability for symbol-by-symbol decoding (i.e., no channel coding). We assume that the constellation has even symmetry; i.e., if $\{a_0, a_1, \ldots\}$ are the positive constellation points, then the negative points are $\{\ldots, -a_1, -a_0\}$. We also assume that the a_i are integers; this constraint may be relaxed, but we do not gain much.

The design algorithm is recursive. That is, if $a_0, a_1, \ldots, a_{k-1}$ have already been chosen, then a_k is chosen such that the following conditions are satisfied:

$$\Pr(\ldots, a_0, a_1, \ldots, a_{k-1} \text{ decoded} \mid a_k \text{ sent}) < \frac{P_e}{2} \tag{9a}$$

$$\Pr(a_k \text{ decoded} \mid a_{k-1} \text{ sent}) < \frac{P_e}{2} \tag{9b}$$

where P_e is the desired target SEP for each constellation point. Note that by design, the single-sided error probabilities (the left-hand error probability in (9a) and the right-hand error probability in (9b)) are smaller than half of the target SEP P_e. This ensures that the total error probability is less than P_e. The recursion begins by finding the y_0 that satisfies $\Pr(-a_0 \text{decoded} \mid a_0 \text{sent}) < (P_e/2)$ and $\Pr(a_0 \text{ decoded} \mid -a_0 \text{ sent}) < (P_e/2)$.

The left-hand error probability $\Pr(\ldots, a_0, a_1, \ldots, a_{k-1}$ decoded $\mid a_k$ sent) of (9a) may be calculated as follows:

$$\Pr(\ldots, a_0, a_1, \ldots, a_{k-1} \text{ decoded} \mid a_k \text{ sent}) = \int_{-\infty}^{\infty} \Pr(\ldots, a_0, a_1, \ldots, a_{k-1} \text{ decoded} \mid a_k \text{ sent}, e) P_E(e)\, de \tag{10}$$

where e denotes the echo.

In Fig. 12, we show an assumed Gaussian distribution for noise centered about the point $y_k + \mathrm{echo}$. The area under the distribution beyond the quantizer threshold is the left-hand error

probability of (9a) or (10). From this, we can derive the following:

$$\Pr(\ldots, a_0, a_1, \ldots, a_{k-1} \text{ decoded} \mid a_k \text{ sent}, e) = Q\left(\frac{(a_k + e - \text{Threshold})}{\sigma_n}\right) \quad (11)$$

Here, "Threshold" is the μ-law quantizer threshold, where the μ-law level higher (resp. lower) than this threshold will be decoded as a_k (resp. a_{k-1}).

Equation (11) provides the term inside the integral in (10). The integration over e in (10) can be approximated by a sum over small intervals of e for calculation. For the probability of echo $P_E(e)$, we have assumed a Gaussian distribution. (The constellation would be different if we assumed a different distribution for echo.)

The right-hand error probability $\Pr(a_k, a_{k+1}, \ldots$ decoded $\mid a_{k-1}$ sent) of (9b) may be calculated similarly.

This recursive process continues until a_k reaches the largest quantization level.

In summary, the constellation design algorithm is as follows.

1) Find the minimum a_0 that satisfies $\Pr(-a_0$ decoded $\mid a_0$ sent$) < (P_e/2)$ and $\Pr(a_0$ decoded $\mid -a_0$ sent$) < (P_e/2)$.
2) Set $k = 1$.
3) Find the minimum a_k that satisfies $\Pr(\ldots, a_0, a_1, \ldots, a_{k-1}$ decoded $|a_k$ sent$) < (P_e/2)$ and $\Pr(a_k, a_{k+1}, \ldots$ decoded $\mid a_{k-1}$ sent$) < (P_e/2)$.
4) If $a_k <$ largest A/$\mu -$ law value, set $k = k + 1$ and go to Step 3; else STOP.

For example, here is a constellation designed under the assumption that the noise and echo distributions are Gaussian with $\sigma_{\mathrm{n}} = 7$ and $\sigma_{\mathrm{e}} = 150$, and with no digital impairments (only positive values are shown).

{37, 113, 192, 275, 361, 450, 544, 646, 755, 870, 988, 1108, 1229, 1351, 1479, 1634, 1804, 1982, 2164, 2348, 2532, 2716, 2900, 3084, 3268, 3452, 3722, 4022, 4331, 4640, 4949, 5258, 5567, 5876, 6185, 6494, 6803, 7112, 7422}.

We can use a similar algorithm for constellation design with channel coding. The only difference is in how to calculate the left-hand and right-hand error probabilities of (9a) and (9b). The exact error probabilities depend on the particular code being used, and are hard to calculate precisely. In practice, we use an error-probability bound, such as that of [10], instead of the exact error probability.

Finally, because RBS impairments usually occur with period six and different digital impairments require different constellations, V.92 allows up to six constellations to be defined. The jth level in constellation c is denoted by a_j^c. In V.92, the digital modem designs the constellations based on the channel characteristics such as echo, noise variance, and RBS impairments that it learned during initial training time. It forwards the constellations to the analog modem for use during data transmission.

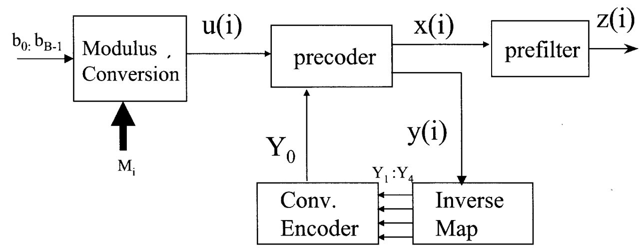

Fig. 13. V.92 analog modem transmitter block diagram.

IV. Channel Coding

Channel coding may be combined with our precoding scheme to achieve higher data rates or greater noise margins. Since decoding is performed on the channel output sequence $y(i)$, the coded sequences $y(i)$ should have good distance properties.

While a novel coding scheme tailored to the PCM upstream application might be possible, we have found that the 4-D trellis codes used for Recommendation V.34 work well, although perhaps not optimally, when the constellation is designed as in the previous section. In V.92, the same trellis codes as in V.34 [11] were adopted to reduce the time and effort of both standardization and product development.

Fig. 13 is a block diagram of all major elements of the V.92 analog modem transmitter.

The data symbols $u(i)$ are generated from the user input bit sequence using 12-symbol modulus conversion [2] with bases $M_k,\ 0 \le k \le 11$. The block size of 12 was chosen to accommodate both period-six base constellations and 4-D trellis codes.

Our precoding scheme is based on the indexes of the constellation points rather than their levels. It is, therefore, natural to combine our precoding scheme with trellis coding as in V.34, except using indexes rather than levels.

The convolutional encoder operates exactly as in V.34, and produces the parity bit Y_0 [11] once every four-symbol period. The inverse map in Fig. 13 operates similarly to the inverse map used in V.34, except that it is based on constellation indexes rather than levels.

As explained in Section II, each data symbol $u(i)$ represents an equivalence class $E(u(i)) = \{a^{i \bmod 6}{}_j | j = u + zM_{i \bmod 12}, z \text{ integer}\}$, where $i \bmod 6$ is the constellation index and j is the symbol index within that constellation.

To combine precoding with 4-D trellis coding, the equivalence class definition is extended as follows. Let $k = i \bmod 4$ be a cyclic time index that indicates the symbol position in the four-symbol trellis frame. Then $E(u)$ is defined as shown in the equation at the bottom of the page. This definition ensures that $y(i)$, the output of the channel in the absence of echo and noise, will be a sequence in the trellis code. A 4-tuple of indexes $\{j_0, j_1, j_2, j_3\}$ is defined to be even or odd according to whether their sum is even or odd. The equivalence class definition of (12) makes the 4-tuple $\{j_0, j_1, j_2, j_3\}$ even or odd according to whether Y_0 is 0 or 1. Therefore, the proposed equivalence class definition, together with feedback through the inverse map and the convolutional encoder, guarantees that $y(i)$ is a valid trellis code sequence.

$$E(u(i)) = \begin{cases} \left\{a_{j_i}^{i \bmod 6} | j_i = u(i) + zM_{i \bmod 12}, z \text{ integer}\right\}, & \text{for } i \bmod 4 = 0, 1, 2 \\ \left\{a_{j_i}^{i \bmod 6} | j_i = 2u(i) + 2zM_{i \bmod 12} + (j_{i-3} + j_{i-2} + j_{i-1} + Y_0) \bmod 2, z \text{ integer}\right\}, & \text{for } i \bmod 4 = 3 \end{cases} \quad (12)$$

V. Discussion and Simulations

In this section, we give simulation results and compare the performance of our PCM upstream transmission system to that of [5].

We first show that both our system and the system given in [5] can be understood using equivalence classes. As shown in the previous section, our proposed transmission system defines an equivalence class at the output of the analog channel, i.e., for $y(i)$. Our proposed system defines an equivalence class such that the constellation has multiple points for each symbol. We then use generalized THP to force a certain point at the output of the channel. Moreover, although V.92 defines the equivalence classes in a 1-D constellation, our scheme can be extended to multiple dimensions.

The system proposed in [5] only uses $N-1$ out of N symbols. If $N=6$, for example, it can be thought as defining an equivalence class for the data $\{a_1, a_2, a_3, a_4, a_5\}$ in a 6-D constellation as $\{a_1, a_2, a_3, a_4, a_5, \text{ any}\}$, where "any" means the decoder does not care about the sixth value. In other words, to send the information $\{a_1, a_2, a_3, a_4, a_5\}$, the output of the analog channel can be $\{a_1, a_2, a_3, a_4, a_5, \text{ any}\}$. This can be thought as expanding the constellation by employing one extra symbol for every five symbols. To obtain a channel output of $\{a_1, a_2, a_3, a_4, a_5, \text{ any}\}$ when the data is $\{a_1, a_2, a_3, a_4, a_5\}$, a MIMO preequalization scheme is used in [5].

The theoretical performance of a precoding system thus depends only on the definition of equivalence classes. Note that the base constellation does not depend on what equivalence class definition is employed; therefore, any precoding scheme can use an optimal constellation as defined in Section III.

Without specifying what kind of preequalization scheme is used, the upstream precoding problem may be restated as follows. Minimize the transmit power, i.e., energy of z, assuming y is in the equivalence class of u and $y(i) = c(i)^* z(i)$

$$\underset{\vec{y}}{\mathrm{Min}}\ \text{Energy}\ (\vec{z}),\ \text{s.t.}\ \vec{y} = \vec{c} * \vec{z} \text{ and } \vec{y} \in \text{Equivalence class}\ (\vec{u}). \tag{13}$$

As can be seen from this equation, the only factor affecting this minimization is the equivalence class definition. Either type of preequalization, i.e., DFE-type preequalization, as in our system, or MIMO system as in [5], can then be used in the transmitter to force the resulting point $y(i)$ at the output of the channel.

VI. Conclusions

We have outlined a new transmission scheme for PCM upstream that can achieve significantly higher rates than 33.6 kb/s. This scheme employs generalized THP with nonuniform PAM constellations, and may be combined with trellis coding. A novel constellation design algorithm has been developed. This scheme has been adopted in ITU Recommendation V.92.

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In 2000, he cofounded Airvana Inc., Chelmsford, MA, developing IP-based wireless infrastructure equipment, where he is currently the Chief Technical Officer. Previously, he was a General Manager of the Home Networking Business Unit with Motorola, Mansfield, MA, and was a Vice President of Technology with Motorola, responsible for the development of advanced technologies in high-speed data transmission and multimedia systems. He has been an active participant in the standardization of voiceband modems in TIA and ITU, and played a key role in the development of the V.34, V.90 and V.92 standards. He holds over 30 patents.

Les Brown graduated from the University of Toronto, Totonto, ON, Canada, in 1972 with the B.A.Sc. degree and in 1977 with the M.A.Sc. degree.

For the past 22 years, he has specialized in wire-line data communication technologies, including voiceband modems, DSL modems, and telephone-line-based home networking. From 1981–2001, he worked with Motorola ISG, Mansfield, MA, where he was involved in all facets of modem development. As a Member of Technical Staff, he represented Motorola ISG in modem-related standards committees, holding several positions of leadership, including Chairman of TIA TR-30.1 and Rapporteur for Question 11 (PCM modems) in ITU-T Study Group 16. He is currently with Centillium Communications, Streetsville, ON, Canada, responsible for coordinating their DSL modem standards activities.

G. David Forney, Jr. (S'59–M'61–F'73) received the B.S.E. degree in electrical engineering from Princeton University, Princeton, NJ, in 1961, and the M.S. and Sc.D. degrees in electrical engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA, in 1963 and 1965, respectively.

From 1965–99 he was with the Codex Corporation, which was acquired by Motorola, Inc. in 1977, and its successor, the Motorola Information Systems Group, Mansfield, MA. Since 1996, he has been Bernard M. Gordon Adjunct Professor at MIT.

Dr. Forney was Editor of the IEEE TRANSACTIONS ON INFORMATION THEORY from 1970 to 1973. He was a member of the Board of Governors of the IEEE Information Theory Society during 1970–76 and 1986–94, and was President in 1992. He has been awarded the 1970 IEEE Information Theory Group Prize Paper Award, the 1972 IEEE Browder J. Thompson Memorial Prize Paper Award, the 1990 IEEE Donald G. Fink Prize Paper Award, the 1992 IEEE Edison Medal, the 1995 IEEE Information Theory Society Claude E. Shannon Award, the 1996 Christopher Columbus International Communications Award, and the 1997 Marconi International Fellowship. In 1998 he received an IT Golden Jubilee Award for Technological Innovation, and two IT Golden Jubilee Paper Awards. He was elected a Fellow of the IEEE in 1973, a member of the National Academy of Engineering (U.S.A.) in 1983, a Fellow of the American Association for the Advancement of Science in 1993, an honorary member of the Popov Society (Russia) in 1994, a Fellow of the American Academy of Arts and Sciences in 1998, and a member of the National Academy of Sciences (U.S.A.) in 2003.

Sepehr Mehrabanzad (S'80–M'81) was born in Tehran, Iran, in 1960. He received the B.S. degree in applied mathematics and the B.S.E.E. degree in 1982, and the M.S.E.E degree in 1984, all from the Georgia Institute of Technology, Atlanta.

He was a member of the Applied Research Group at Racal-DataComm from 1984 to 1989, where he focused on packet voice, digital speech processing, and lease line modems. From 1989 to 2000, he was with the Signal Processing Research Group, Motorola-Codex, and then Motorola Labs, both in Mansfield, MA, where he worked on digital speech processing, echo cancellation, fax remodulation, cable modems, dial-up modems, and soft modems. He led the K56Flex/V.90/V.92 modem development within Motorola and represented Motorola in ITU and TR-30. He joined Airvana Inc., Chelmsford, MA, in May 2000, where he was architect of the first-generation lxEV-DO base station. Currently, he is the Senior Technical Manager of the BTS Software Development Group with Airvana. He holds over 11 issued/pending U. S. and foreign patents.

EXHIBIT J

INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

V.32

(03/93)

DATA COMMUNICATION OVER THE TELEPHONE NETWORK

A FAMILY OF 2-WIRE, DUPLEX MODEMS OPERATING AT DATA SIGNALLING RATES OF UP TO 9600 bit/s FOR USE ON THE GENERAL SWITCHED TELEPHONE NETWORK AND ON LEASED TELEPHONE-TYPE CIRCUITS

ITU-T Recommendation V.32

(Previously "CCITT Recommendation")

FOREWORD

The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the International Telecommunication Union. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, established the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

ITU-T Recommendation V.32 was revised by the ITU-T Study Group XVII (1988-1993) and was approved by the WTSC (Helsinki, March 1-12, 1993).

NOTES

1 As a consequence of a reform process within the International Telecommunication Union (ITU), the CCITT ceased to exist as of 28 February 1993. In its place, the ITU Telecommunication Standardization Sector (ITU-T) was created as of 1 March 1993. Similarly, in this reform process, the CCIR and the IFRB have been replaced by the Radiocommunication Sector.

In order not to delay publication of this Recommendation, no change has been made in the text to references containing the acronyms “CCITT, CCIR or IFRB” or their associated entities such as Plenary Assembly, Secretariat, etc. Future editions of this Recommendation will contain the proper terminology related to the new ITU structure.

2 In this Recommendation, the expression “Administration” is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

CONTENTS

A FAMILY OF 2-WIRE, DUPLEX MODEMS OPERATING AT DATA SIGNALLING RATES OF UP TO 9600 bit/s FOR USE ON THE GENERAL SWITCHED TELEPHONE NETWORK AND ON LEASED TELEPHONE-TYPE CIRCUITS

(Malaga-Torremolinos, 1984, amended Melbourne, 1988 and Helsinki, 1993)

1 Introduction

This family of modems is intended for use on connections on general switched telephone networks (GSTNs) (see Note 1) and on point-to-point leased telephone-type circuits. The principal characteristics of the modems are as follows:

a) Duplex mode of operation on GSTN and 2-wire point-to-point leased circuits (see Note 2).

b) Channel separation by echo cancellation techniques.

c) Quadrature amplitude modulation for each channel with synchronous line transmission at 2400 bauds.

d) Any combination of the following data signalling rates may be implemented in the modems:

9600 bit/s synchronous (optional),

4800 bit/s synchronous (mandatory),

2400 bit/s synchronous (for further study).

e) At 9600 bit/s, two alternative modulation schemes, one using 16 carrier states and one using trellis coding with 32 carrier states, are provided for in this Recommendation. However, modems providing the 9600 bit/s data signalling rate shall be capable of interworking using the 16-state alternative.

f) Exchange of rate sequences during start-up to establish the data rate, coding and any other special facilities.

g) Optional provision of an asynchronous mode of operation in accordance with Recommendations V.14 or V.42.

NOTES

1 On international GSTN connections that utilize circuits that are in accord with Recommendation G.235 (16-channel terminal equipments), it may be necessary to employ a greater degree of equalization within the modem than would be required for use on most national GSTN connections.

2 The transmit and receive rates in each modem shall be the same. The possibility of asymmetric working remains for further study.

2 Line signals

2.1 Carrier frequency

The carrier frequency is to be 1800 ± 1 Hz. No separate pilot tones are to be provided. The receiver must be able to operate with received frequency offsets of up to ± 7 Hz.

2.2 Transmitted spectrum

The transmitted power level must conform to Recommendation V.2. With continuous binary ones applied to the input of the scrambler, the transmitted energy density at 600 Hz and 3000 Hz should be attenuated 4.5 ± 2.5 dB with respect to the maximum energy density between 600 Hz and 3000 Hz.

2.3 Modulation rate

The modulation rate shall be 2400 bauds ± 0.01%.

2.4 Coding

2.4.1 Signal element coding for 9600 bit/s

Two alternatives are defined.

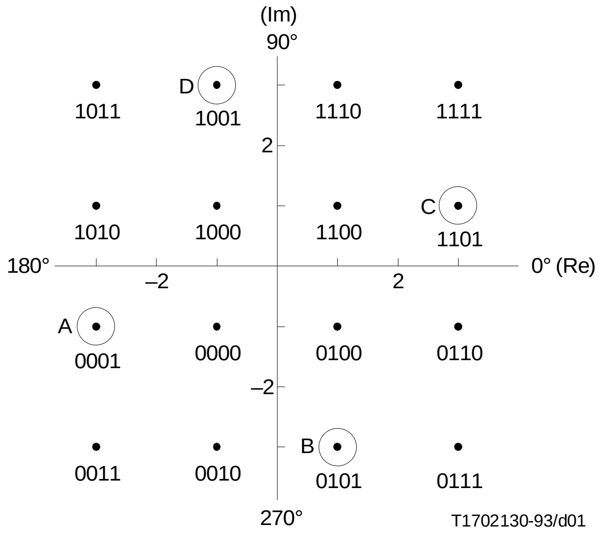
2.4.1.1 Nonredundant coding

The scrambled data stream to be transmitted is divided into groups of 4 consecutive data bits. The first two bits in time $Q1_n$ and $Q2_n$ in each group, where the subscript n designates the sequence number of the group, are differentially encoded into $Y1_n$ and $Y2_n$ according to Table 1. Bits $Y1_n$, $Y2_n$, $Q3_n$ and $Q4_n$ are then mapped into the coordinates of the signal state to be transmitted according to the signal space diagram shown in Figure 1 and as listed in Table 3.

TABLE 1/V.32

Differential quadrant coding for 4800 bit/s and for nonredundant coding at 9600 bit/s

Inputs		Previous outputs		Phase quadrant change	Outputs		Signal state for 4800 bit/s
$Q1_n$	$Q2_n$	$Y1_{n-1}$	$Y2_{n-1}$		$Y1_n$	$Y2_n$	
0	0	0	0	+ 90º	0	1	B
0	0	0	1		1	1	C
0	0	1	0		0	0	A
0	0	1	1		1	0	D
0	1	0	0	0º	0	0	A
0	1	0	1		0	1	B
0	1	1	0		1	0	D
0	1	1	1		1	1	C
1	0	0	0	+180º	1	1	C
1	0	0	1		1	0	D
1	0	1	0		0	1	B
1	0	1	1		0	0	A
1	1	0	0	+270º	1	0	D
1	1	0	1		0	0	A
1	1	1	0		1	1	C
1	1	1	1		0	1	B



NOTE – The binary numbers denote $Y1_n$ $Y2_n$ $Q3_n$ $Q4_n$

FIGURE 1/V.32

16-point signal structure with nonredundant coding for 9600 bit/s and subset A B C and D of states used at 4800 bit/s and for training

2.4.1.2 Trellis coding

The scrambled data stream to be transmitted is divided into groups of 4 consecutive data bits. As shown in Figure 2, the first two bits in time $Q1_n$ and $Q2_n$ in each group, where the subscript n designates the sequence number of the group, are first differentially encoded into $Y1_n$ and $Y2_n$ according to Table 2. The two differentially encoded bits $Y1_n$ and $Y2_n$ are used as input to a systematic convolutional encoder which generates a redundant bit $Y0_n$. This redundant bit and the 4 information-carrying bits $Y1_n$, $Y2_n$, $Q3_n$ and $Q4_n$ are then mapped into the coordinates of the signal element to be transmitted according to the signal space diagram shown in Figure 3 and as listed in Table 3.

2.4.2 Signal element coding for 4800 bit/s

The scrambled data stream to be transmitted is divided into groups of 2 consecutive data bits. These bits, denoted $Q1_n$ and $Q2_n$, where $Q1_n$ is the first in time, and the subscript n designates the sequence number of the group, are differentially encoded into $Y1_n$ and $Y2_n$ according to Table 1. Figure 1 shows the subset A, B, C and D of signal states used for 4800 bit/s transmission.

2.4.3 Signal element coding for 2400 bit/s

For further study.

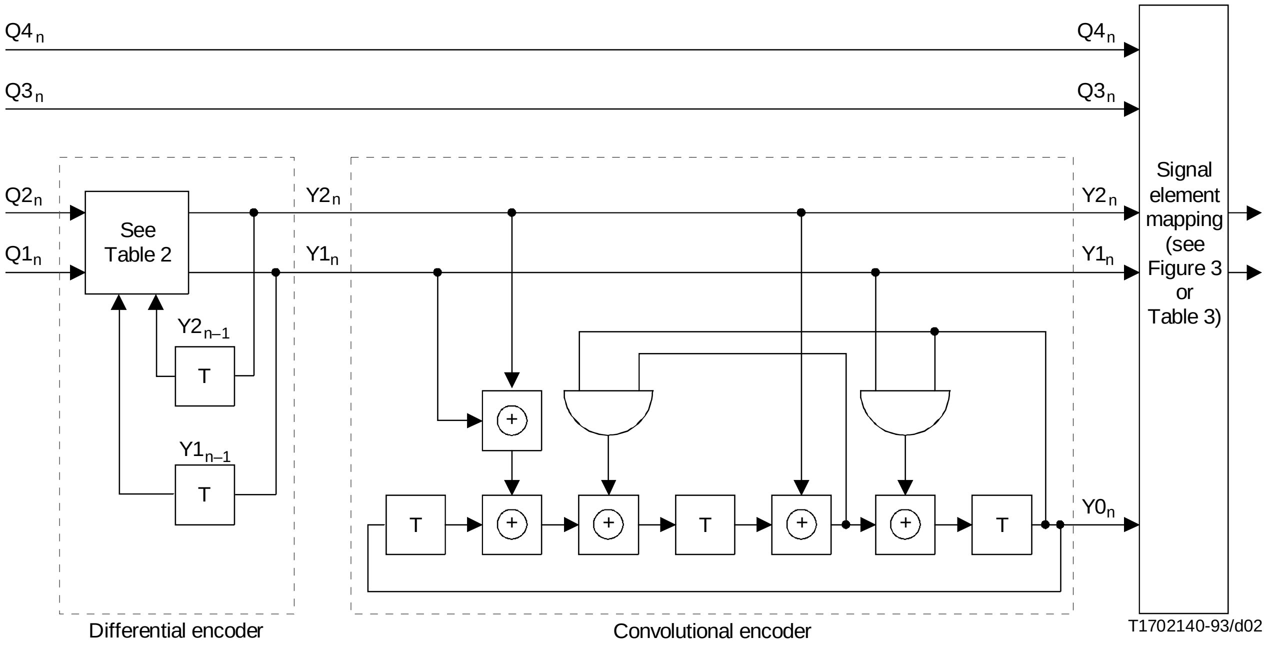
3 Interchange circuits

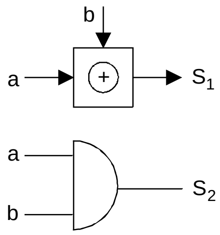
3.1 List of interchange circuits

These are listed in Table 4.

3.2 Transmit data

The modems shall accept synchronous data from the DTE on circuit 103 under control of circuit 113 or 114.





Symbol truth table

a	b	S_1	S_2
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

FIGURE 2/V.32

Trellis coding at 9600 bit/s

3.3 Receive data

The modems shall pass synchronous data to the DTE on circuit 104 under the control of circuit 115.

3.4 Timing arrangements

Clocks shall be included in the modems to provide the DTE with transmitter signal element timing on circuit 114 and receiver signal element timing on circuit 115. The transmitter timing may originate in the DTE and be transferred to the modem via circuit 113. In some applications it may be necessary to slave the transmitter timing to the receiver timing inside the modem.

3.5 Data rate control

Data rate selection may be by switch (or similar means) or alternatively by circuit 111. In cases where three different data signalling rates are implemented in a modem, a manual selector may be provided which determines the two data signalling rates selected by circuit 111.

The ON condition of circuit 111 selects the higher data signalling rate and the OFF condition of circuit 111 selects the lower data signalling rate.

TABLE 2/V.32

Differential encoding for use with trellis coded alternative at 9600 bit/s

Inputs		Previous outputs		Outputs	
$Q1_n$	$Q2_n$	$Y1_{n-1}$	$Y2_{n-1}$	$Y1_n$	$Y2_n$
0	0	0	0	0	0
0	0	0	1	0	1
0	0	1	0	1	0
0	0	1	1	1	1
0	1	0	0	0	1
0	1	0	1	0	0
0	1	1	0	1	1
0	1	1	1	1	0
1	0	0	0	1	0
1	0	0	1	1	1
1	0	1	0	0	1
1	0	1	1	0	0
1	1	0	0	1	1
1	1	0	1	1	0
1	1	1	0	0	0
1	1	1	1	0	1

3.6 Circuit 106

After the start-up and retrain sequences, circuit 106 must follow the state of circuit 105 within 2 ms.

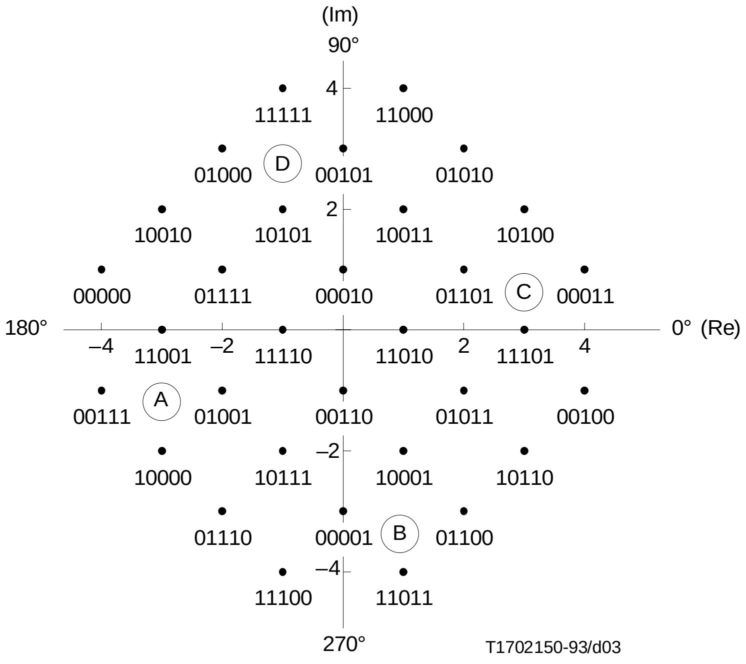
3.7 Circuit 109

OFF to ON and ON to OFF transitions of circuit 109 should occur solely in accordance with the operating sequences defined in 5. Thresholds and response times are inapplicable because a line signal detector cannot be expected to distinguish wanted received signals from unwanted talker echoes.

3.8 Electrical characteristics of interchange circuits

3.8.1 Use of electrical characteristics conforming to Recommendation V.28 is recommended together with the connector and pin assignment plan specified by ISO 2110.

NOTE – Manufacturers may wish to note that the long-term objective is to replace electrical characteristics specified in Recommendation V.28, and that Study Group XVII has agreed that the work shall proceed to develop a more efficient, all-balanced, interface for the V-Series application which minimizes the number of interchange circuits.



NOTE – The binary numbers denote $Y0_n\ Y1_n\ Y2_n\ Q3_n\ Q4_n$.

FIGURE 3/V.32

32-point signal structure with trellis coding for 9600 bit/s and states A B C and D used at 4800 bit/s and for training

3.9 Fault condition on interchange circuits

See 7/V.28 for association of the receiver failure detection types.

3.9.1 The DTE should interpret a fault condition on circuit 107 as an OFF condition using failure detection type 1.

3.9.2 The DCE should interpret a fault condition on circuits 105 and 108 as an OFF condition using failure detection type 1.

3.9.3 All other circuits not referred to above may use failure detection types 0 or 1.

4 Scrambler and descrambler

A self-sychronizing scrambler/descrambler shall be included in the modem. Each transmission direction uses a different scrambler. The method of allocating the scramblers/descramblers is described in 4.1. According to the direction of transmission, the generating polynomial is:

Call mode modem generating polynomial: (GPC) $= 1 + x^{-18} + x^{-23}$; or

Answer mode modem generating polynomial: (GPA) $= 1 + x^{-5} + x^{-23}$

At the transmitter, the scrambler shall effectively divide the message data sequence by the generating polynomial. The coefficients of the quotients of this division, taken in descending order, form the data sequence which shall appear at the output of the scrambler. At the receiver the received data sequence shall be multiplied by the scrambler generating polynomial to recover the message sequence.

TABLE 3/V.32

The two alternative signal-state mappings for 9600 bit/s

Coded inputs (see Table 1 or Table 2 with Figure 2)					Nonredundant coding		Trellis coding	
(Y0)	Y1	Y2	Q3	Q4	Re	Im	Re	Im
0	0	0	0	0	–1	–1	–4	1
	0	0	0	1	–3	–1	0	–3
	0	0	1	0	–1	–3	0	1
	0	0	1	1	–3	–3	4	1
	0	1	0	0	1	–1	4	–1
	0	1	0	1	1	–3	0	3
	0	1	1	0	3	–1	0	–1
	0	1	1	1	3	–3	–4	–1
	1	0	0	0	–1	1	–2	3
	1	0	0	1	–1	3	–2	–1
	1	0	1	0	–3	1	2	3
	1	0	1	1	–3	3	2	–1
	1	1	0	0	1	1	2	–3
	1	1	0	1	3	1	2	1
	1	1	1	0	1	3	–2	–3
	1	1	1	1	3	3	–2	1
1	0	0	0	0			–3	–2
	0	0	0	1			1	–2
	0	0	1	0			–3	2
	0	0	1	1			1	2
	0	1	0	0			3	2
	0	1	0	1			–1	2
	0	1	1	0			3	–2
	0	1	1	1			–1	–2
	1	0	0	0			1	4
	1	0	0	1			–3	0
	1	0	1	0			1	0
	1	0	1	1			1	–4
	1	1	0	0			–1	–4
	1	1	0	1			3	0
	1	1	1	0			–1	0
	1	1	1	1			–1	4

TABLE 4/V.32

Interchange circuit (see Note 1)		Notes
No.	Description	
102	Signal ground or common return	
103	Transmitted data	
104	Received data	
105	Request to send	
106	Ready for sending	
107	Data set ready	
108/1 or	Connect data set to line	2
108/2	Data terminal ready	2
109	Data channel received line signal detector	
111	Data signalling rate selector (DTE source)	3
112	Data signalling rate selector (DCE source)	3
113	Transmitter signal element timing (DTE source)	5
114	Transmitter signal element timing (DCE source)	6
115	Receiver signal element timing (DCE source)	6
125	Calling indicator	4
140	Loopback/maintenance test	
141	Local loopback	
142	Test indicator	

NOTES

1 All interchange circuits which are provided shall comply with the functional and operational requirements of Recommendation V.24. All interchange circuits shall be properly terminated in the data terminal equipment and in the data circuit-terminating equipment in accordance with the appropriate Recommendation for electrical characteristics (see 3.8).

2 This circuit shall be capable of operation as circuit 108/1 or circuit 108/2 depending on its use. Operation of circuits 107 and 108/1 shall be in accordance with 4.4/V.24.

3 This circuit is not essential when only one data signalling rate is implemented in the modem.

4 This circuit is for use with the general switched telephone network only.

5 When the modem is not operating in a synchronous mode at the interface, any signals on this circuit shall be disregarded. Many DTEs operating in an asynchronous mode do not have a generator connected to this circuit.

6 When the modem is not operating in a synchronous mode at the interface, this circuit shall be clamped to the OFF condition. Many DTEs operating in an asynchronous mode do not terminate this circuit.

4.1 Scrambler/descrambler allocation

4.1.1 General switched telephone network (GSTN)

On the general switched telephone network, the modem at the calling data station (call mode) shall use the scrambler with the GPC generating polynomial and the descrambler with the GPA generating polynomial. The modem at the answering data station (answer mode) shall use the scrambler with the GPA generating polynomial and the descrambler with the GPC generating polynomial. In some situations, however, such as when calls are established on the GSTN by operators, bilateral agreement on call mode/answer mode allocation will be necessary.

4.1.2 Point-to-point leased circuits

Scrambler/descrambler allocation and call mode and answer mode designation on point-to-point leased circuits will be by bilateral agreement between Administrations or users.

5 Operating procedures

5.1 Recommendation V.25 automatic answering sequence

The Recommendation V.25 automatic answering sequence shall be transmitted from the answer mode modem on international GSTN connections. The transmission of the sequence may be omitted on point-to-point leased circuits or on national connections on the GSTN where permitted by Administrations. In this event, the answer mode modem shall initiate transmission as in the retrain procedure specified in 5.5.

5.2 Receiver conditioning signal

The receiver conditioning signal shall be used in the start-up and retrain procedures defined in 5.4 and 5.5. The signal consists of three segments:

5.2.1 Segment 1, denoted by S in Figures 4 and 5, consists of alternations between states A and B as shown in Figure 1, for a duration of 256 symbol intervals.

5.2.2 Segment 2, denoted by $\overline{\mathrm{S}}$ in Figures 4 and 5, consists of alternations between states C and D as shown in Figure 1, for a duration of 16 symbol intervals.

The transition from segment 1 to segment 2 provides a well-defined event in the signal that may be used for generating a time reference in the receiver.

5.2.3 Segment 3, denoted by TRN in Figures 4 and 5, is a sequence derived by scrambling binary ones at a data rate of 4800 bit/s with the scrambler defined in 4. During the transmission of this segment, the differential quadrant encoding shall be disabled. The initial state of the scrambler shall be all zeros, and a binary one applied to the input for the duration of segment 3. Successive dibits are encoded onto transmitted signal states.

The first 256 transmitted signal states are determined from the state of the first bit occurring (in time) in each dibit. When this bit is ZERO, signal state A is transmitted; when this bit is ONE, signal state C is transmitted. Depending on whether the modem is in call or answer mode, the scrambler output patterns and corresponding signal states will then begin as below, where the bits and the signal states are shown in time sequence from left to right.

Call mode modem:

GPC:	11	11	11	11	11	11	11	11	11	00	00	01	11	11	11
	C	C	C	C	C	C	C	C	C	A	A	A	C	C	C

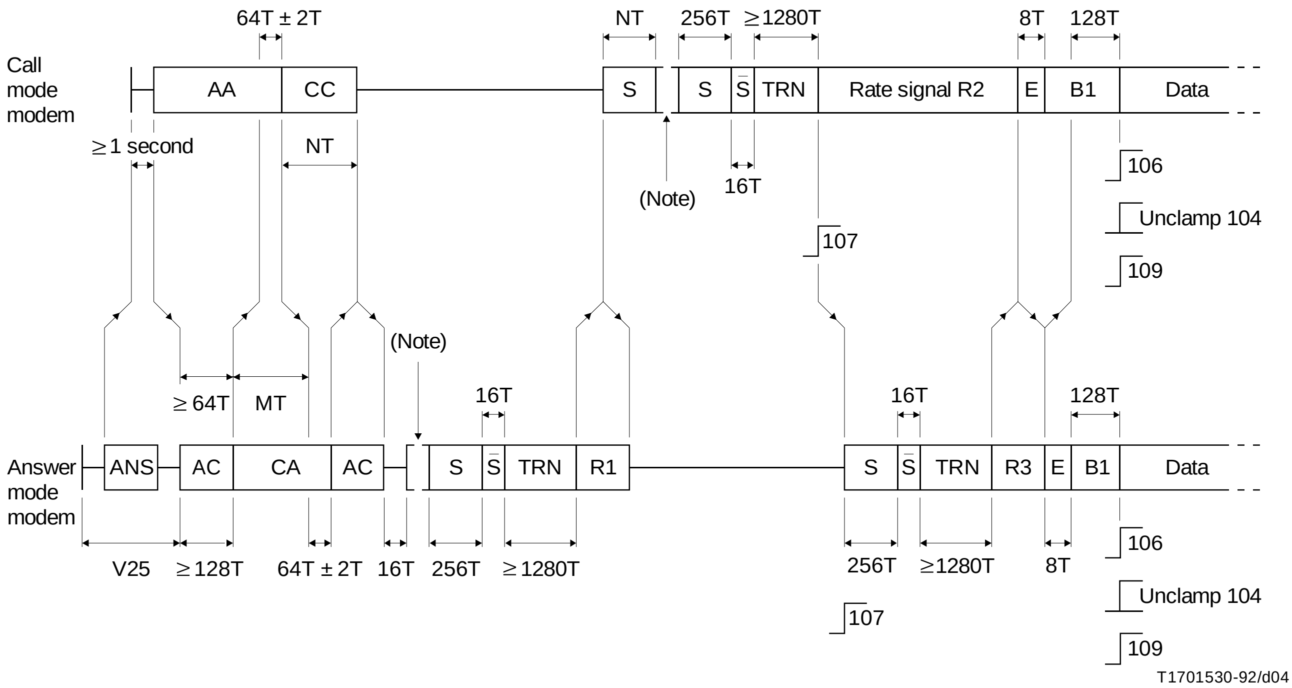
Answer mode modem:

GPA:	11	11	10	00	00	11	11	10	00	00	11	10	01	11	11
	C	C	C	A	A	C	C	C	A	A	C	C	A	C	C

Immediately after 256 such symbols, successive scrambled dibits are encoded onto transmitted signal states in accordance with Table 5 directly without differential encoding for the remainder of segment 3. The duration of segment 3 shall be at least 1280 and not exceed 8192[1)] symbol intervals.

Segment 3 is intended for training the adaptive equalizer in the receiving modem and the echo canceller in the transmitting modem.

[1)] The maximum duration of 8192 symbol intervals is for further study.



AC	Signal states ACAC..AC for an even number of symbol intervals T; similarly with CA, AA and CC.
MT, NT	Round-trip delays observed from answer and call modems respectively, including 64T ± 2T modem turn round delay.
S, S̄	Signal states ABAB..AB, CDCD..CD.
TRN	Scrambled ones at 4800 bit/s with dibits encoded directly to states A, B, C and D as defined in 5.2.3.
R1, R2, R3	Each a repeated 16-bit rate sequence at 4800 bit/s scrambled and differentially encoded as in Table 1.
E	A single 16-bit sequence marking and following the end of a whole number of 16-bit rate sequences in R2 and R3.
B1	Binary ones scrambled and encoded as for the subsequent transmission of data.

NOTE – The inclusion of a special echo canceller training sequence at this point is optional (see 5.4, Note 3).

FIGURE 4/V.32

Start-up procedure

5.3 Rate signal

The rate signal consists of a whole number of repeated 16-bit binary sequences, as defined in Table 6, scrambled and transmitted at 4800 bit/s with dibits differentially encoded as in Table 1. The differential encoder shall be initialized using the final symbol of the transmitted TRN segment.

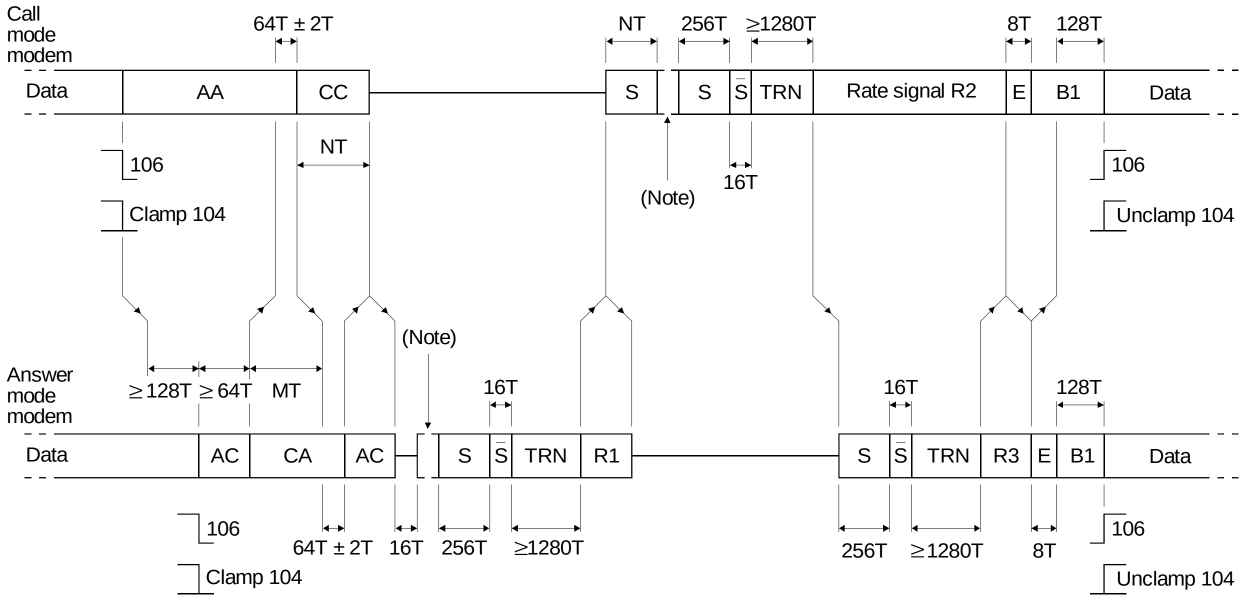
The first two bits and each successive dibit of the rate sequence shall be encoded to form the transmitted signal states.

5.3.1 Detecting a rate signal

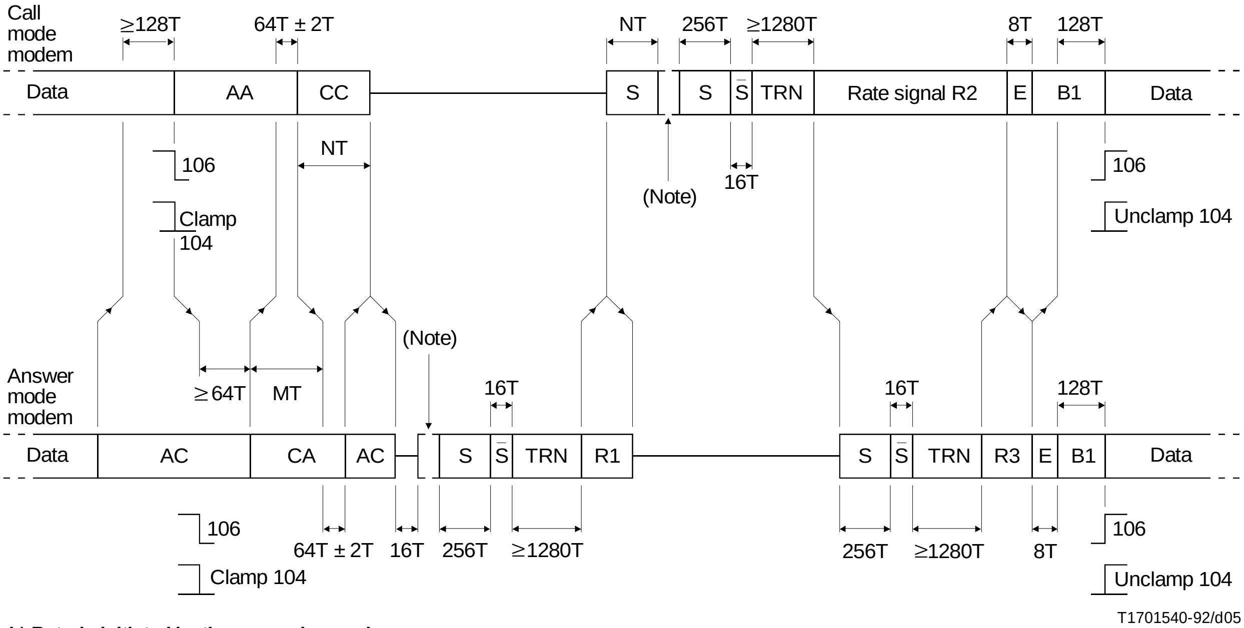
The minimum requirement for detection is the receipt of two consecutive identical 16-bit sequences each with bits B0-3, B7, 11 and 15 conforming to Table 6.

5.3.2 Ending the rate signal

In order to mark the end of transmission of any rate signal other than R1 (Figure 4), the modem shall first complete the transmission of the current 16-bit rate sequence, and then transmit one 16-bit sequence E, coded as shown in Table 7.



a) Retrain initiated by the calling modem



b) Retrain initiated by the answering modem

AC	Signal states ACAC..AC for an even number of symbol intervals T; similarly with CA, AA and CC.
MT, NT	Round-trip delays observed from answer and call modems respectively, including 64T ± 2T symbol intervals modem turn round delay.
S, S̄	Signal states ABAB..AB, CDCD..CD.
TRN	Scrambled ones at 4800 bit/s with dibits encoded directly to states A, B, C and D as defined in 5.2.3.
R1, R2, R3	Each a repeated 16-bit rate sequence at 4800 bit/s scrambled and differentially encoded as in Table 1.
E	A single 16-bit sequence marking and following the end of a whole number of 16-bit rate sequences in R2 and R3.
B1	Binary ones scrambled and encoded as for the subsequent transmission of data.

NOTE – The inclusion of a special echo canceller training sequence at this point is optional (see 5.4, Note 3).

FIGURE 5/V.32

TABLE 5/V.32

Encoding for TRN segment after the first 256 symbols

Dibit	Signal state
00	A
01	B
11	C
10	D
NOTE – Signal states A, B, C and D are shown in Figure 1.	

TABLE 6/V.32

Coding of the 16-bit rate sequence

B0	B1	B2	B3	B4	B5	B6	B7	B8	B9	10	11	12	13	14	15	B0	B1	B2	B3	B4	etc.
0	0	0	0	–	–	–	1	–	–	–	1	–	–	–	1	0	0	0	0	–	

B0-3, B7, 11, 15	For synchronizing on a received rate signal
B4	1 denotes ability to receive data at 2400 bit/s (see Note 1)
B5	1 denotes ability to receive data at 4800 bit/s
B6	1 denotes ability to receive data at 9600 bit/s
B4-6	0 0 0 calls for a GSTN cleardown
B8	1 denotes availability of trellis coding/decoding at the highest data rate indicated in B4-6 (see Note 1)
B9-14	0 0 1 0 0 0 denotes absence of special operational modes (see Note 2)

NOTES

1 The combination of B4 equal one and B8 equal one indicates V.32 *bis* operation.

2 The use of bits B9, 10 and 12 through 14 is defined in Recommendation V.32 *bis* for data signalling rates other than 4800 and 9600 bit/s.

TABLE 7/V.32

Coding of signal E

B0	B1	B2	B3	B4	B5	B6	B7	B8	B9	10	11	12	13	14	15
1	1	1	1	–	–	–	1	–	–	–	1	–	–	–	1

B4-14	As in Table 6, except that the only data rate and coding to be indicated shall relate to the transmission of scrambled binary ones immediately following signal E

5.4 Start-up procedure

The procedure for achieving synchronism between the calling modem and the answering modem on international GSTN connections is shown in Figure 4. The procedure includes the estimating of round-trip delay from each modem, the training of echo cancellers and receivers initially with half-duplex transmissions, and the exchanging of rate signals for automatic bit-rate and mode selection.

5.4.1 Call mode modem

After receiving the answer tone for a period of at least 1 s as specified in Recommendation V.25, the modem shall be connected to line (see Note 1 in 5.4.2) and shall condition the scrambler and descrambler in accordance with 4.1.

The modem shall repetitively transmit carrier state A as shown in Figure 1.

The modem shall be conditioned to detect (see Note 2 in 5.4.2) one of two incoming tones at frequencies 600 ± 7 Hz and 3000 ± 7 Hz, and subsequently to detect a phase reversal in that tone.

On detection of one such phase reversal, the modem shall be conditioned to detect a second phase reversal in the same tone, start a counter/timer and change to repetitively transmitting state C as shown in Figure 1. The time delay between the reception of this phase reversal at the line terminals and the transmitted AA to CC transition appearing at the line terminals shall be 64 ± 2 symbol periods.

On detection of a second phase reversal in the same incoming tone, the modem shall stop the counter/timer and cease transmitting.

When the modem detects an incoming S sequence (see 5.2), it shall proceed to train its receiver, and then seek to detect at least two consecutive identical 16-bit rate sequences as defined in Table 6.

On detection of the rate signal (R1), the modem shall transmit an S sequence for a period NT already estimated by the counter/timer.

After this period has expired (see Note 3 in 5.4.2), the modem shall transmit the receiver conditioning signal as defined in 5.2, starting with an S sequence for 256 symbol intervals.

Transmission of the TRN segment of the receiver conditioning signal may be extended in order to ensure a satisfactory level of echo cancellation (see Note 4 in 5.4.2).

After the TRN segment, the modem shall apply an ON condition to circuit 107 and transmit a rate signal (R2) in accordance with 5.3 to indicate the currently available data rates and whether trellis coding and/or other special operational modes are available. R2 shall exclude rates and operational modes not appearing in the previously received rate signal R1. It is recommended that R2 should also take account of the likely receiver performance with the particular GSTN connection. If it appears that satisfactory performance cannot be attained at any of the available data rates, then R2 should be used to call for a GSTN cleardown in accordance with Table 6.

Transmission of R2 shall continue until an incoming rate signal R3 is detected. The modem shall then, after completing its current 16-bit rate sequence, transmit a single 16-bit sequence E in accordance with 5.3.2 indicating the data rate, coding and any special operational modes called for in R3. If, however, R3 is calling for a GSTN cleardown in accordance with Table 6, then the call modem shall disconnect from line and effect a cleardown.

The modem shall then transmit continuous scrambled binary ones at the data rate and with the coding called for in R3, and apply the appropriate condition to circuit 112. If trellis coding according to 2.4.1.2 is to be used, the initial states of the delay elements of the convolution encoder shown in Figure 2 should be set to zero.

On detecting an incoming 16-bit E sequence as defined in 5.3.2, the modem shall condition itself to receive data at the rate and with the coding indicated by the incoming E sequence. After a delay of 128 symbol intervals, it shall apply an ON condition to circuit 109, and unclamp circuit 104.

The modem shall then enable circuit 106 to respond to the condition of circuit 105 and be ready to transmit data.

5.4.2 Answer mode modem

On connection to line, the modem shall condition the scrambler and descrambler in accordance with 4.1, and transmit the Recommendation V.25 answer sequence. Means, defined in Recommendation V.25, of disabling network echo cancellers and/or truncating the answer tone may be employed.

After the Recommendation V.25 answer sequence, the modem shall transmit alternate carrier states A and C as shown in Figure 1.

After alternate states A and C have been transmitted for an even number of symbol intervals greater than or equal to 128 *and* an incoming tone has been detected at 1800 ± 7 Hz for 64 symbol periods (see Note 5), the modem shall be conditioned to detect a phase reversal in the incoming tone, start a counter/timer, and change to transmitting alternate carrier states C and A for an even number of symbol intervals.

On detecting a phase reversal in the incoming tone, the modem shall stop the counter/timer and, after transmitting a state A, revert to transmitting alternate states A and C. The time delay between the reception of this phase reversal at the line terminals and the transmitted CA to AC transition appearing at the line terminals shall be 64 ± 2 symbol periods.

When an amplitude drop is detected in the incoming tone, the modem shall cease transmitting for a period of 16 symbol intervals and then (see Note 3) transmit the receiver conditioning signal as defined in 5.2.

Transmission of the TRN segment of the receiver conditioning signal may be extended in order to ensure a satisfactory level of echo cancellation (see Note 4).

After the TRN segment, the modem shall transmit a rate signal (R1) in accordance with 5.3 to indicate the data rates, coding and any special operational modes currently available in the answer modem and associated DTE.

On detection of an incoming S sequence, the modem shall cease transmitting.

The modem shall wait for a period MT already estimated by the counter/timer and then, if an incoming S sequence persists, or when an S sequence reappears (see Note 3), the modem shall proceed to train its receiver.

After training its receiver, the modem shall seek to detect at least two consecutive identical incoming 16-bit rate sequences as defined in 5.3.

On detection of a rate signal (R2), the modem shall apply an ON condition to circuit 107 and transmit a second receiver conditioning signal as defined in 5.2.

After the TRN segment, the modem shall transmit a second rate signal (R3) in order to indicate the data rate, coding and any special operational modes to be used by both modems. The data rate and operational modes selected by R3 shall be within those indicated by R2. It is recommended that R3 should also take account of the likely performance of the answer modem receiver with the particular GSTN connection established. If R2 is calling for a GSTN cleardown (see Table 6) and/or if it appears that satisfactory performance cannot be attained by the answer modem at any of the available data rates, then R3 should call for a GSTN cleardown, in accordance with Table 6.

When the modem detects an incoming 16-bit E sequence as defined in 5.3.2, it shall condition itself to receive data at the rate and with the coding indicated by the E sequence.

The modem shall complete the current 16-bit rate sequence and then transmit a single 16-bit E sequence indicating the data rate and coding to be used in the subsequent transmission of scrambled binary ones. If trellis coding according to 2.4.1.2 is to be used, then the initial states of the delay elements of the convolution encoder shown in Figure 3 should be set to zero.

The modem shall transmit scrambled binary ones for 128 symbol intervals, then enable circuit 106 to respond to the condition of circuit 105 and be ready to transmit data.

The modem shall also apply an ON condition to circuit 109 and unclamp circuit 104.

NOTES

1 Once an incoming tone is detected at 600 ± 7 Hz or 3000 ± 7 Hz, the calling modem should proceed with the start-up sequence even if no 2100 Hz tone has been detected.

2 In some cases, the incoming tones may be preceded by a special pattern which may last up to 3050 ms.

3 The TRN segment in the receiver conditioning signal is suitable for training the echo canceller in the transmitting modem. Alternatively, it is acceptable to precede the receiver conditioning signal by a sequence which can be used specifically for training the echo canceller, but which need not be defined in detail in the Recommendation. The echo cancellation sequence (if used) must maintain energy transmitted to line to hold network echo control devices disabled (as required). In order to avoid confusion with Segments 1 or 2 of the receiver conditioning signal defined in 5.2, the echo cancellation sequence shall produce a transmitted signal such that the sum of its power in the three 200 Hz bands centred at 600 Hz, 1800 Hz and 3000 Hz is at least 1 dB less than its power in the remaining bandwidth. This applies for the relative power averaged over any 6 ms time interval. The duration of this signal must not exceed 8192[2)] symbol intervals.

4 Manufacturers are cautioned that a period of 650 ms is needed for training any network echo cancellers conforming to Recommendation G.165, that may be encountered on GSTN connections.

5 The answering modem may disconnect from the line if the 1800 ± 7 Hz tone is not detected following transmission of the segment AC. However, to assure compatibility with manual originating data stations, it shall not disconnect for at least 3 seconds after the segment AC has been transmitted.

5.5 Retrain procedure

A retrain may be initiated during data transmission if either modem incorporates a means of detecting unsatisfactory signal reception. Diagram a) of Figure 5 shows a retrain event initiated by the calling modem and diagram b) of Figure 5 shows a retrain event initiated by the answering modem. The procedure is as follows.

5.5.1 Call mode modem

Following detection of unsatisfactory signal reception or detection of one of two tones at frequencies 600 ± 7 Hz and 3000 ± 7 Hz for more than 128 symbol intervals, the modem shall turn OFF circuit 106, clamp circuit 104 to binary one and repetitively transmit carrier state A as shown in Figure 1. It shall then proceed in accordance with 5.4.1 beginning with the third paragraph (see Note in 5.5.2).

5.5.2 Answer mode modem

Following detection of unsatisfactory signal reception or detection of a tone of frequency 1800 ± 7 Hz for more than 128 symbol intervals, the modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit alternate carrier states A and C for an even number of symbol intervals not less than 128. It shall then proceed in accordance with 5.4.2 beginning with the third paragraph (see Note).

NOTE – During a retrain, circuit 107 should remain ON.

(The need for a shorter duplex retrain procedure to provide for rapid training of the modem receivers is for further study.)

5.5.3 Operation of circuit 109 during retrain procedure

Circuit 109 shall be maintained in the ON condition except that the OFF condition may optionally be applied if transmission of the AA segment in the Call modem or of the first AC segment in the Answer modem continues for a period exceeding 45 seconds. If the retrain procedure is subsequently completed, the ON condition shall be re-applied to circuit 109 at the time that circuit 104 is unclamped.

[2)] The maximum duration of 8192 symbol intervals is for further study.

6 Testing facilities

Test loops 2 and 3 as defined in Recommendation V.54 should be provided. Provision for test loop 2 shall be as specified for point-to-point circuits.

7 Asynchronous to synchronous conversion protocol – Modes of operation

The modem can be configured for the following modes of operation (modes 2 and 4 are optional):

Mode 1 9600 bit/s ±0.01% synchronous.

Mode 2 9600 bit/s start-stop 8, 9, 10 or 11 bits per character.

Mode 3 4800 bit/s ±0.01% synchronous.

Mode 4 4800 bit/s start-stop 8, 9, 10 or 11 bits per character.

7.1 Transmitter

7.1.1 In the synchronous modes of operation, the modem shall accept synchronous data from the DTE on circuit 103 under control of circuit 113 or circuit 114. The data shall then be scrambled in accordance with 4 and then passed to the modulator for encoding in accordance with 2.4.

7.1.2 In the start-stop modes, the modem shall accept a data stream of start-stop characters from the DTE at a nominal rate of 9600 or 4800 bit/s per second. The start-stop data to be transmitted shall be converted in conformity with Recommendation V.14 to a synchronous data stream suitable for transmission in accordance with 7.1.1.

7.2 Receiver

Demodulated data shall be decoded in accordance with 2.4, then descrambled in accordance with 4 and then passed to the converter in conformity with Recommendation V.14 for regaining the data stream of start-stop characters.

The intracharacter signalling rate provided to the DTE over circuit 104 shall be in the ranges given in Table 8 when operating in the basic, or in the extended signalling rate ranges, respectively.

TABLE 8/V.32

Intracharacter signalling rate range

Data rate	Signalling rate range	
	Basic	Extended
9600 bit/s	9600 to 9696 bit/s	9600 to 9821 bit/s
4800 bit/s	4800 to 4848 bit/s	4800 to 4910 bit/s

Annex A

(This annex forms an integral part of this Recommendation)

Considering that there is a need for some V.32 modems to include the capability of interworking with V.22 and V.22 *bis* modems, the following start-up procedures are recommended. A modem which includes this optional capability will be referred to as a V.32 automode modem.

A.1 Definitions of terms used

ANS The 2100 Hz answer tone defined in Recommendation V.25.

USB1 Unscrambled binary ones modulated by an answering modem as defined in Recommendation V.22 *bis*.

SB1 Scrambled binary ones modulated as defined in Recommendation V.22 *bis*.

S1 Unscrambled double dibit 00 and 11 modulated as defined in Recommendation V.22 *bis*.

AA See Figure 4.

AC See Figure 4.

A.2 Interworking of duplex modems

Modems conforming with V.32, V.22 *bis* and V.22 (operating in mode 1 or 2 only) could interwork with a dedicated automode modem implementing a procedure for sensing the capabilities of a remote modem and employing the appropriate modulation scheme.

The procedure can follow two courses. The calling modem makes a decision as to whether its signal AA was detected by the answering modem during the V.25 answer sequence. If the decision indicates that signal AA was detected, the course followed is as depicted in Figure A.1. Otherwise, the course followed is as depicted in Figures A.2 and A.3.

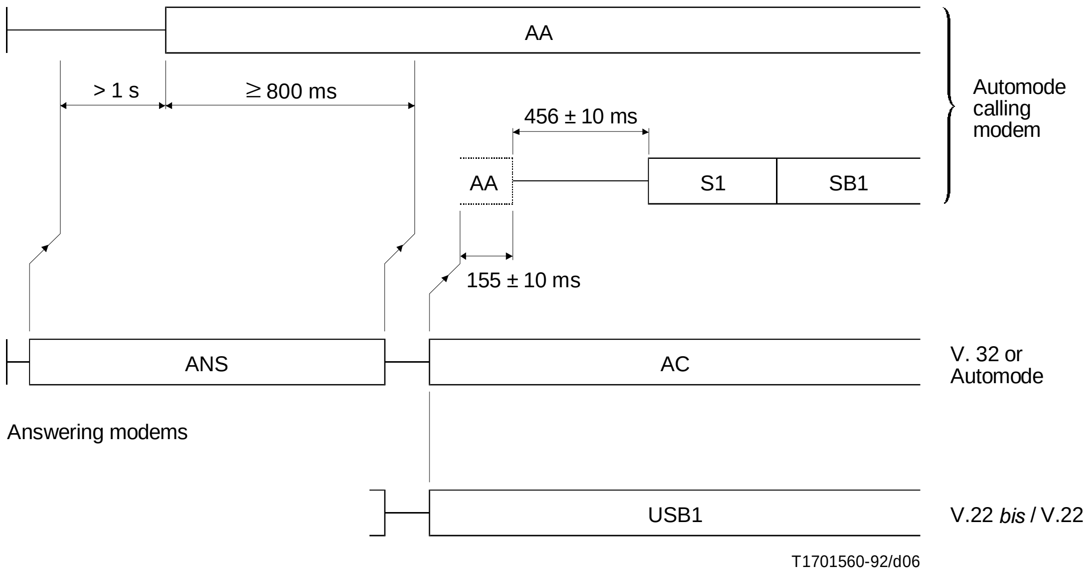


FIGURE A.1/V.32

Procedure when a calling automode modem measures at least 800 ms of signal ANS after it has started transmitting signal AA

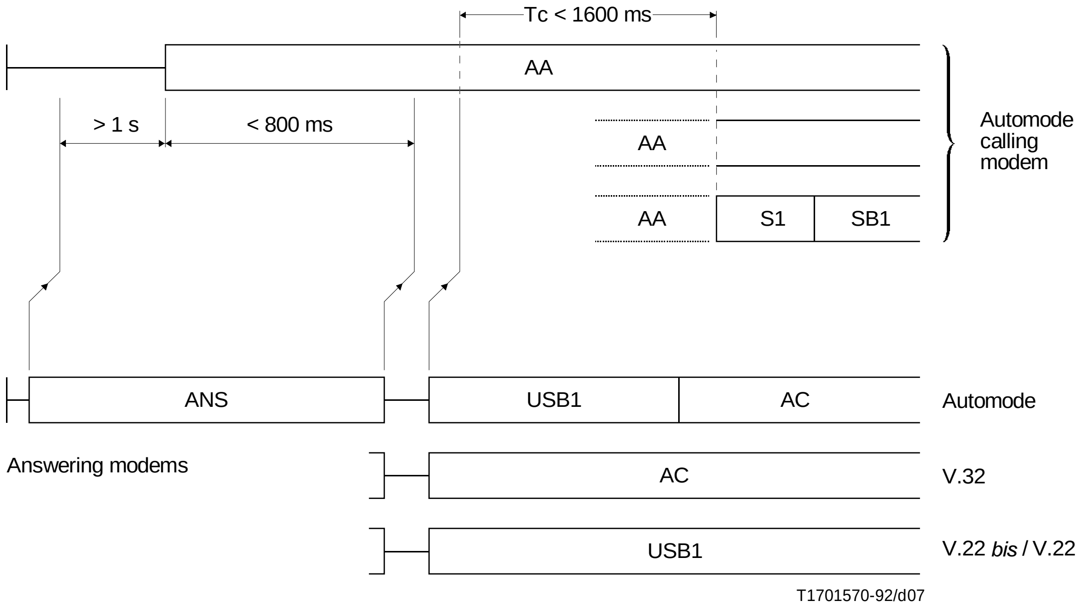


FIGURE A.2/V.32

Procedure when a calling automode modem measures less than 800 ms of signal ANS after it has started transmitting signal AA

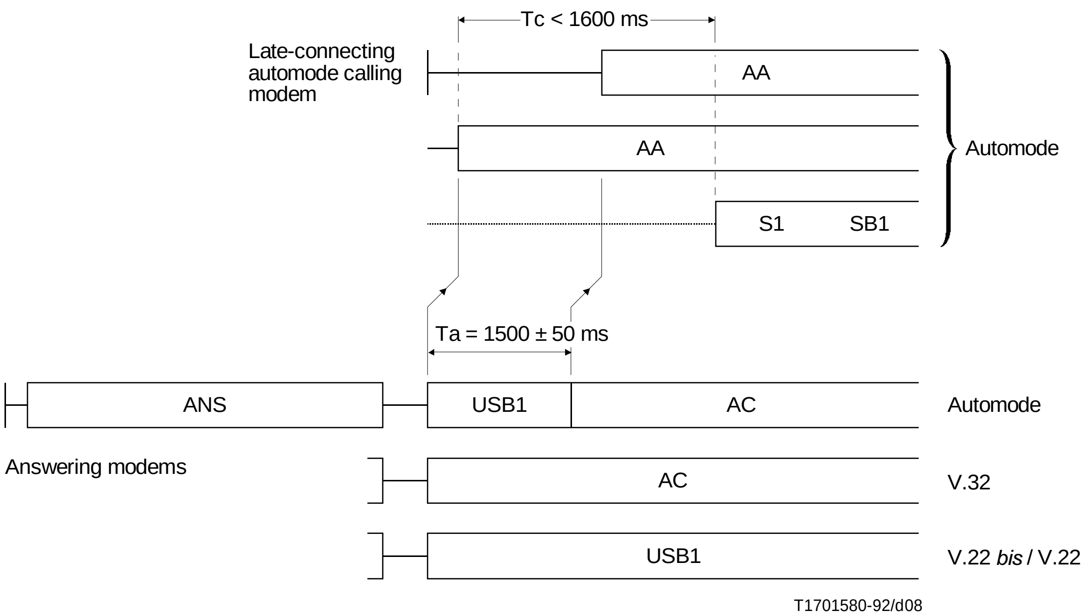


FIGURE A.3/V.32

Procedure when a calling automode modem connects after the V.25 answer sequence

A.2.1 Operation of the calling automode modem

On connection to line, the calling modem shall initially remain silent and shall condition its receiver to detect any of three signals: AC, USB1, ANS.

A.2.1.1 If signal AC is detected, the modem shall begin transmission of signal AA and continue as defined in 5.4.1.

A.2.1.2 If signal USB1 is detected, the modem shall start a timer.

When the elapsed time exceeds Tc, where Tc > 1600 ms, if signal USB1 is again detected, the modem shall first transmit signal S1 in the low band, then begin transmitting signal SB1 and then continue with Recommendation V.22 *bis* beginning at 6.3.1.1.1 c). If at any time signal AC is detected, the modem shall continue as defined in 5.4.1.

A.2.1.3 If signal ANS is detected for a period of at least 1 second, the modem shall begin transmission of signal AA, condition its receiver to prepare to detect either signal USB1 or signal AC, and start a timer to measure the duration of the remaining answer tone.

On the detection of the end of signal ANS, the timer is stopped. The timer value shall not include the 75 ms silent period defined in Recommendation V.25.

If, following the 75 ms silent period, signal AC is detected, the modem shall continue with the V.32 training sequence beginning at 5.4.1. When signal USB1 is detected for 155 ± 10 ms (see Note 1 in A.2.2), subsequent procedures shall depend on the duration of signal ANS measured by the timer. If the duration was greater than 800 ms, the modem shall first stop transmitting AA, then, after 456 ms silent period, shall transmit signal S1 in the low band, then begin transmitting signal SB1 and then continue with Recommendation V.22 *bis* beginning at 6.3.1.1.1 c). Otherwise, the modem shall proceed in accordance with A.2.1.2.

A.2.2 Operation of the answering automode modem

On connection to line, the answering modem shall transmit the V.25 answer sequence and condition its receiver to detect signal AA.

If signal AA is detected at any time during the transmission of the V.25 answer sequence, the modem shall continue as defined 5.4.2 at the second paragraph.

If signal AA is not detected during the transmission of the V.25 answer sequence, the modem shall begin transmitting signal USB1, condition its receiver to detect in the low band either of the two signals S1, SB1 and start a timer.

If either of the two signals S1, SB1 are detected in the low band, the modem shall continue as defined in Recommendation V.22 *bis* beginning at 6.3.1.1.2 b). Otherwise, when the elapsed time exceeds Ta, where Ta = 1500 ± 50 ms (see Note 2), the modem shall proceed as defined in 5.4.2 beginning at the second paragraph.

NOTES

1 There is a small possibility that some GSTN signalling systems could produce brief interruptions in transmission during a period in which signal AA may be inhibiting the effect of the 1800 Hz V.22 *bis*/V.22 guard tone transmitted with signal USB1. See Figure A.4.

2 The transmission of USB1 for this maximum duration is recommended in order to avoid signal AC being received and possibly misinterpreted as a loss of carrier by some implementations of V.22 *bis* modems. Some implementations of 1984 and 1988 V.32 modems might be sensitive to more than 294 ms of USB1 (see Note 2 in 5.4.2).

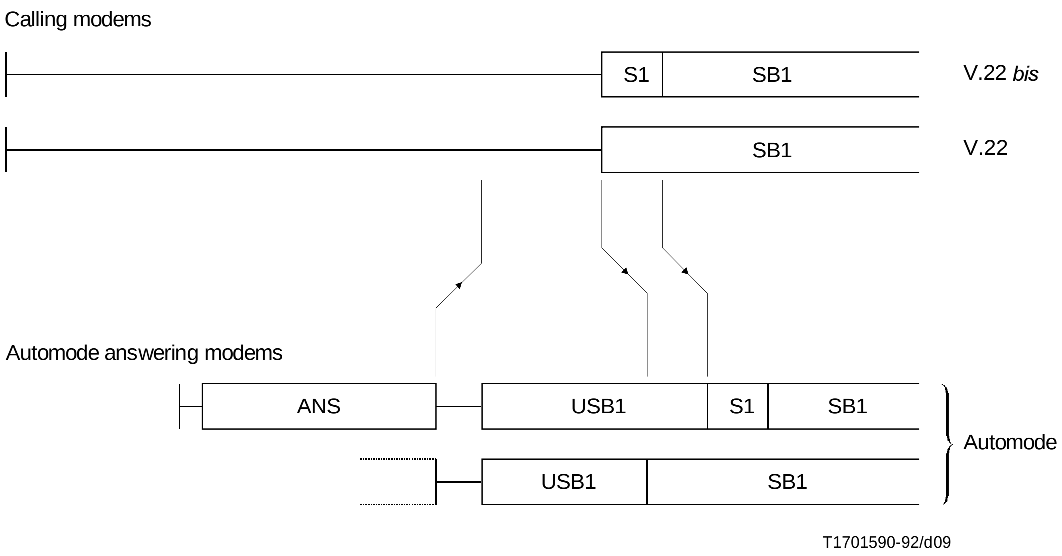


FIGURE A.4/V.32

Answering automode modem interworking with a calling V.22 *bis* or V.22 modem

Appendix I

Interworking procedure for echo cancelling modems

(This appendix does not form an integral part of this Recommendation)

Considering

– that the V.26 *ter* modem at 2400 bit/s and the V.32 modems at 9600 bit/s and 4800 bit/s are based on the same technique, referred to as echo cancellation;

– that the 1800 Hz carrier frequency is the same for the two modems;

– that there may be a need for a modem, referred to as multimode, able to interwork with V.26 *ter* and V.32 modems;

– that the determination of round-trip delay may be useful in some cases,

the handshaking operating sequence defined in the following subclauses is provided for the information of manufacturers.

I.1 Interworking of echo cancelling modems

The V.32 modems at 9600 bit/s and 4800 bit/s and the V.26 *ter* modems at 2400 bit/s could interwork with a dedicated multimode modem implementing both V.32 and V.26 *ter* capabilities, as illustrated in Table I.1.

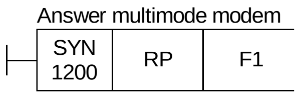
TABLE I.1/V.32

Handshaking compatibility

Answering / Calling	V.26 *ter*	V.32	M (Multimode)
V.26 *ter*	SYN 1200 SYN 1200	F1 Disconnect No energy	SYN 1200 then F1 (Note) SYN 1200
V.32	SYN 1200 disconnect F2 Wait at least T1 = 300 ms	F1 F2	SYN 1200 then F1 (Note)
M (Multimode)	SYN 1200 SYN 1200	F1 Detected transmit F2	SYN 1200 then F1 (Note) F2 or SYN 1200

F1 Tones at 600 ± 7 Hz and 3000 ± 7 Hz generated by alternately transmitting carrier states A and C.
F2 Tone at 1800 ± 7 Hz generated by repetitively transmitting carrier state A.

NOTE – The modem M is distinguished by a special rate pattern.



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I.1.1 Operation of the calling multimode modem

The modem will recognize:

- A V.26 *ter* modem by detecting the 1200 baud synchronization signals followed by a rate pattern and then will proceed as defined in V.26 *ter* (see Figure I.1).

- V.32 modems by the detection of one of two incoming tones at frequencies 600 ± 7 Hz and 3000 ± 7 Hz (see Figure I.2). It will then proceed as defined in 5.4.1.

- A multimode modem by the detection of a special rate pattern assigned to the multimode modem. It will transmit, as shown in Figure I.3, repetitively carrier state A or the synchronizing signals followed by the rate pattern, according to the selected mode of operation: V.32 or V.26 *ter* respectively.

I.1.2 Operation of the answering multimode modem

After the V.25 sequence, the modem will transmit the 1200 baud synchronizing signals followed by its special rate pattern, and then alternate carrier states A and C as defined in Recommendation V.32.

It will recognize during the transmission of these alternate carrier states A and C:

- a V.26 *ter* modem by the detection of the 1200 baud synchronizing signals followed by a rate pattern. It will stop transmitting alternate carrier states A and C and proceed according to Recommendation V.26 *ter* (see Figure I.4);

- V.32 modems by recognizing a tone at 1800 ± 7 Hz and will then proceed as defined in Recommendation V.32 (see Figure I.5).

The case of multimode modems on both answering and calling sides has been considered in I.1.1.

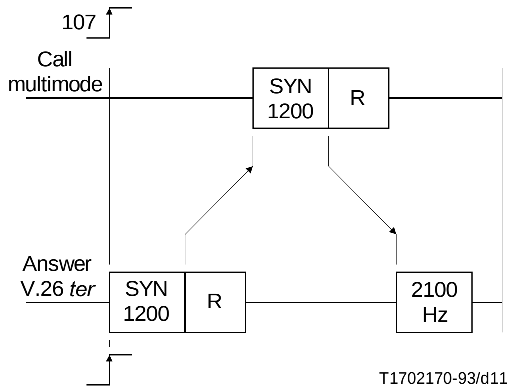

FIGURE I.1/V.32

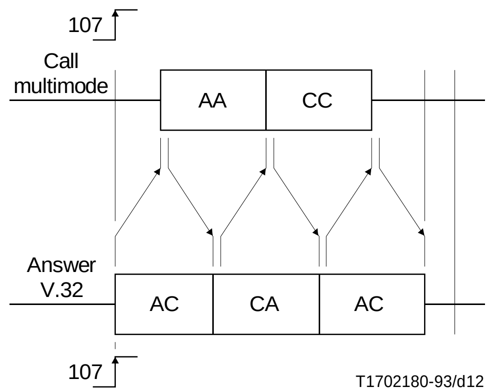

FIGURE I.2/V.32

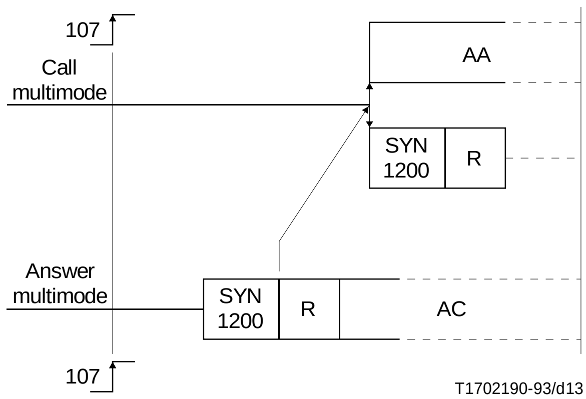

FIGURE I.3/V.32

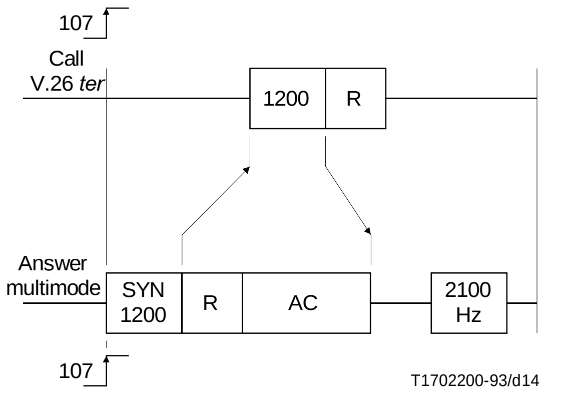

FIGURE I.4/V.32

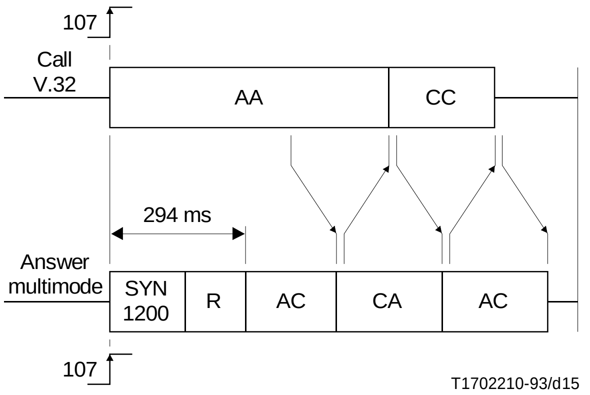

FIGURE I.5/V.32

EXHIBIT K

On Optimal Shaping of Multidimensional Constellations

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***Abstract*—A scheme for the optimal shaping of multidimensional constellations is proposed. This scheme is motivated by a type of structured vector quantizer for memoryless sources, and results in N-sphere shaping of N-dimensional cubic lattice-based constellations. Because N-sphere shaping is optimal in N dimensions, shaping gains higher than those of N-dimensional Voronoi constellations can be realized. While optimal shaping for a large N can realize most of the 1.53 dB total shaping gain, it has the undesirable effect of increasing the size and the peak-to-average power ratio of the constituent 2D constellation. This limits its usefulness for many real world channels which have nonlinearities. The proposed scheme alleviates this problem by achieving optimal constellation shapes for a given limit on the constellation expansion ratio or the peak-to-average power ratio of the constituent 2D constellation. Results of Calderbank and Ozarow on nonequiprobable signaling are used to reduce the complexity of this scheme and make it independent of the data rate with essentially no effect on the shaping gain. Comparisons with Forney's trellis shaping scheme are also provided.**

***Index Terms*—Multidimensional constellations, SVQ shaping, shell mapping, optimal shaping, Voronoi constellations, trellis shaping, constellation expansion.**

I. Introduction

The problem of data transmission is the dual of the quantization problem, and this duality is formally described in [1]. Advances in transmission theory have therefore resulted in useful insight and new quantization techniques (and vice versa). One such example is the use of the idea behind trellis-coded modulation [2], [3] for the quantization of data [4], [5]. Another example is the quantization of memoryless sources using lattice- and trellis-bounded codebooks [1], [6], a topic extensively studied in the context of modulation. This paper applies some of the ideas from a structured vector quantizer for memoryless sources [7] to the optimal shaping of multidimensional constellations.

Shaping of multidimensional constellations has been studied in detail in [8]–[14]. Reference [8] contains an excellent introduction to the problem and discusses cross and generalized cross constellations. Lattice-bounded constellations are considered in [9], and the generalization to trellis-bounded constellations (trellis shaping) is described in [10]. Shaping codes based on nonequiprobable signaling are the topic of [11]–[14]. Most of the terminology in this paper is adopted from [8]. Some of the relevant terms defined there are now briefly described.

A constellation C generally consists of a set of points on an N-dimensional lattice (translate) Λ that are enclosed within a finite region $\mathscr{R}$. The simplest N-dimensional constellation consists of all the points on a cubic lattice enclosed within an N-cube. This is the baseline constellation, and the performance of all the more complex constellations is measured in terms of gains over this constellation. There are two kinds of gains that can be achieved over the baseline system. The first is obtained by using a more densely packed N-dimensional lattice than the N-dimensional cubic lattice and is called the *coding gain* γ_c. The second is the *shaping gain* γ_s that results from using a more spherical bounding region $\mathscr{R}$ than an N-cube. When the region $\mathscr{R}$ is big and encloses a large number of lattice points, the distribution of points in $\mathscr{R}$ can be approximated by a continuous uniform distribution over $\mathscr{R}$. This is the *continuous approximation* and, unless mentioned otherwise, in this paper we assume that it holds. Under the continuous approximation, the coding gain is decoupled from the shaping gain, and both can be realized independently. The topic of coding gain is addressed in [15], and here we focus only on the shaping gain. Shaping gain is defined as the ratio of the average energy of a baseline constellation with the same number of points and based on the same lattice as the given constellation to the average energy of the given constellation. Under the continuous approximation, the shaping gain is the inverse ratio of the average energy of the constellation region $\mathscr{R}$ to the average energy of the region bounded by an N-cube of the same volume as $\mathscr{R}$; this is also referred to as the shaping gain of the region $\mathscr{R}$. The region that has the smallest average energy for a given volume is an N-sphere. For a given N, therefore,

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the shaping gain is bounded by the shaping gain of an N-sphere. The maximum possible shaping gain is $\pi e/6 = 1.423$ (1.53 dB), which is the limit of the N-sphere shaping gain as N becomes large. The shaping gains of the generalized cross constellations described in [8] are limited to about 0.4 dB. Voronoi constellations of known lattices [9] can achieve gains up to 1.1 dB. Simulations in [4] show that trellis shaping can achieve larger gains—1.36 dB with a 256-state trellis. Shaping codes based on nonequiprobable signaling [13], [14] can realize up to 1.2 dB shaping gain.

A *constituent* 2D *constellation* of a given N-dimensional (assuming an even N) constellation C is the set of all values that a given two-dimensional symbol takes as the N-dimensional signal points range through C. The constellation C is called a 2D-*symmetric constellation* if it has the same constituent 2D constellation for all possible pairs of dimensions. In this case, we say that the constituent 2D constellation of C is C_2. For constellations that are not 2D-symmetric, C_2 is taken as the union of all the different constituent 2D constellations. Some attributes of the constituent 2D constellations are important from the viewpoint of implementation with QAM (quadrature amplitude modulation) modems and are described next.

The *shaping constellation expansion ratio* CER_2 of the constituent 2D constellation C_2 of C is defined as the ratio of the size $|C_2|$ of C_2 to the size $|C|^{2/N}$ of the constituent 2D constellation of a baseline N-cube bounded constellation containing the same number of points as in C. Therefore, $\mathrm{CER}_2 = |C_2|/|C|^{2/N}$ and is lower bounded by unity. The *peak-to-average power ratio* (PAR_2) of C_2 is defined as the ratio of the squared distance of the farthest point(s) in C_2 from the origin to the average energy of points in C normalized to two dimensions (assuming all points in C are equally probable). The PAR_2 of the baseline N-cube bounded constellation is 3. For implementation with QAM modems, it is desirable to have both a small PAR_2 and a small CER_2 [8]. Although optimal, N-sphere shaping is undesirable because it results in large CER_2 and PAR_2.

The Voronoi region $\bar{\mathscr{R}}_V(\Lambda) \subset \mathbb{R}^N$ of an N-dimensional lattice Λ is defined as the set of points in $\mathbb{R}^N$ that are at least as close (in the Euclidean distance sense) to the origin as to any other point in the lattice. The conventional approach of bounding the constellation by the Voronoi region of a lattice is based on the fact that the Voronoi regions of some N-dimensional lattices can approximate an N-sphere (especially for large N). In [16], it is shown that algorithmic indexing or labeling of the points in such constellations can be performed (look-up tables are generally impractical for a large N), leading to modest complexity encoding/decoding algorithms. Forney's trellis shaping scheme [10] uses the "Voronoi region" of a trellis code to shape the constellation. A trellis code is the generalization of a finite-dimensional lattice to an infinite-dimensional sequence space. For a given complexity, trellis shaping achieves higher shaping gains than lattice-bounded constellations. Although the lattice- and trellis-bounded constellations can achieve a significant portion of the maximum possible shaping gain of 1.53 dB, this usually comes at the cost of an equally significant increase in CER_2 and PAR_2. Bounds obtained in [8] (see Figs. 2 and 3 of this paper) show that it is, at least in principle, possible to realize the same shaping gain as some of the best known lattices and trellises with a significantly smaller CER_2 and PAR_2.

For lattice- and trellis-bounded constellations, peak constraints [10], [17] can be introduced to significantly reduce the CER_2 and PAR_2 with only a minimal loss in shaping gain. Although the peak constraints make these schemes useful for practical implementation, they do not result in the best tradeoff between CER_2 (or PAR_2) and shaping gain.

In this paper, we describe the optimal constellation boundary for a given constraint on the constellation expansion ratio or the peak-to-average power ratio. Two algorithms for indexing the points of such optimally shaped constellations are also given. These algorithms are motivated by the indexing algorithms of a structured vector quantizer called the scalar-vector quantizer (SVQ) [7], [18], and therefore the shaping scheme described in this paper is called SVQ shaping. The first indexing algorithm (Algorithm 1) requires no multiplications (only additions and subtractions), but has a higher storage complexity than the second algorithm (Algorithm 2) which requires multiplications. The storage and computational complexities of these algorithms are polynomial in constellation dimension, but exponential in rate. We use the results of Calderbank and Ozarow (C&O) on nonequiprobable signaling [11] to reduce the complexities of these algorithms and make them independent of the constellation data rate. Compatability of SVQ shaping with trellis coding is also demonstrated.

Even though our indexing algorithms were motivated by scalar-vector quantizers, it was pointed out by the reviewers that the second algorithm (Algorithm 2) presented here is similar to the indexing scheme of Lang and Longstaff [19] called shell mapping. In [19], Lang and Longstaff use shell mapping to enumerate the Leech lattice points enclosed in a 24-dimensional sphere. However, they do not consider constellation boundaries that maximize shaping gain for a given constraint on the CER_2 (or PAR_2).

Reviewers also brought to our attention the work of Khandani and Kabal (K&K) [20], [21] and the work of Kschischang and Pasupathy (K&P) [22] which were also under review at that time. Although performed independently, both of these are in some ways similar to the present work. Both K&K and K&P also describe the optimal constellation boundary for a given CER_2 and PAR_2. For addressing the constellation points, K&K use a table look-up algorithm which decomposes the problem into a hierarchy of simpler lower dimensional addressing problems. To reduce the look-up table size, they too use the C&O results [11]. However the memory requirement of their algorithm is relatively large for applications such

as voiceband modems. The indexing scheme used by K&P is a generalization of the shell mapping algorithm of Lang and Longstaff, but they do not capitalize on the C&O results to make the complexity of their scheme independent of the data rate (at high rates).

This paper is organized as follows. In the next section, we define a class of constellations called SVQ constellations, and give two algorithms for indexing the points of these constellations. We show that the optimal N-sphere shaped constellation is a special case of SVQ constellation, and so the indexing algorithms of the SVQ constellation can be used for N-sphere shaping. Generalized cross constellations [8] and binary shaping codes [11] are also shown to be special cases of the SVQ constellation. In Section III, we describe constellations that result in the best tradeoff between shaping gain and CER_2 or PAR_2, and show that these can also be represented as SVQ constellations. Shaping at high rates is considered in Section IV, followed by an example of a high-rate constellation in Section V. In Section VI, it is shown that SVQ shaping can be combined with coding. This is important because coding gain is more significant than shaping gain. Comparisons with trellis shaping are provided in Section VII.

II. SVQ Shaping of Constellations

In this section, we first define a class of constellations which are called SVQ constellations. These constellations are so named because they are defined similar to the codebook of the scalar-vector quantizer (SVQ) introduced in [7], [18]. Two algorithms to index the points of SVQ constellations are also described. These algorithms are motivated by the indexing algorithms of the scalar-vector quantizer. The reason for starting with the general class of SVQ constellations is that many useful constellations are special cases of the SVQ constellations. These include N-sphere shaped constellations and the optimal constellations of Section III. A shaping scheme that uses an SVQ constellation and its indexing algorithms will be referred to as SVQ shaping.

A. SVQ Constellations

In QAM transmission, the channel alphabet $\mathscr{Q}$ consists of a finite set of points (channel symbols) from a 2D (cubic) lattice. An N-dimensional constellation is usually a subset of $\mathscr{Q}^{N/2}$, the $N/2$-fold Cartesian product of $\mathscr{Q}$ with itself. The constituent 2D constellation of the N-dimensional constellation is then a subset of $\mathscr{Q}$. In the general case, consider a d-dimensional channel. For QAM transmission, $d = 2$. Let $\mathscr{Q} \equiv \{q_1, q_2, \cdots, q_n\}$ be the set of n, d-dimensional channel symbols. These symbols are usually taken to be the n smallest energy points on some d-dimensional lattice Λ_d. To every channel symbol q_i; $i \in J_n \equiv \{1, 2, \cdots, n\}$ in $\mathscr{Q}$, assign a positive integer cost l_i. The cost could, for example, be the normalized energy of the channel symbol. Define $\mathscr{L} \equiv \{l_1, l_2, \cdots, l_n\}$ to be the set of (positive integer) costs. An N-dimensional ($N = md$) SVQ-constellation $\mathscr{Z}$ consists of those points in $\mathscr{Q}^m$ which have a total cost no greater than a threshold L, where the total cost of a point in $\mathscr{Z}$ is defined as the sum of the costs of its m d-dimensional components. The threshold L is chosen such that $\mathscr{Z}$ contains (at least) 2^{mr} points, where r is the rate of the constellation in bits/d-dimension. This is formally described by the following definition.

Definition: An N-dimensional SVQ constellation $\mathscr{Z}$ derived from an alphabet $\mathscr{Q}$ and the corresponding set of costs $\mathscr{L}$ is given as

$$\mathscr{Z} = \{z \equiv (z_1, z_2, \cdots, z_m) \in \mathscr{Q}^m : l_{f(z_1)} + l_{f(z_2)} + \cdots + l_{f(z_m)} \le L\} \quad (1)$$

where the index function $f\colon \Theta \to J_n$ is defined as

$$f(q_i) = i, \qquad i \in J_n. \quad (2)$$

For a rate r bits/d-dimension constellation, the threshold L is selected as the smallest integer such that the cardinality of $\mathscr{Z}$ is no less than 2^{mr}.

Since this paper deals mainly with shaping and not coding, the lattice Λ_d will be assumed to be cubic, i.e., the alphabet $\mathscr{Q}$ is assumed to consist of points on a d-dimensional cubic lattice. Compatibility with trellis coding will be discussed in Section VI. Also, except where mentioned otherwise, we shall be dealing with QAM systems and assume $d = 2$.

It is easy to show that the generalized cross constellation [8] is a special case of the SVQ constellation. This can be done by dividing a 2D cross constellation $\mathscr{Q}$ into inner and outer points and assigning a cost of, say, 1 to the inner points and 2 to the outer points. If the threshold L is chosen as $m + 1$, no N-dimensional constellation point contains more than one outer point of $\mathscr{Q}$. The binary shaping codes [11] can similarly be represented as SVQ constellations. Also, by taking $\mathscr{Q}$ to be an appropriate subset of the integers Z and the cost $l_i = q_i^2$, an N-sphere shaped cubic-lattice constellation can be described as an SVQ constellation.

The above definition is very similar to the definition of the scalar-vector quantizer [7], [18], and the constellation here corresponds to the codebook of the quantizer. This is because shaping of the codebook boundary is also important in the quantization of memoryless sources [1], [7]. In general, the best codebook boundary depends on the probability distribution of the source to be quantized. For Gaussian sources, the optimal codebook boundary (in N dimensions) is an N-sphere. The scalar-vector quantizer implements optimal codebook boundaries for an important class of memoryless sources and algorithmically indexes the codevectors. Defining SVQ constellations as above enables us to use the indexing algorithms of the scalar-vector quantizer to index the constellation points. In this sense, the SVQ constellation is a transmission dual of the scalar-vector quantizer.

Before we discuss the indexing of constellation points, we present an algorithm to determine the threshold L given the rate r of the SVQ constellation.

B. Determination of the Threshold L

For a given set of costs $\mathscr{L}$ and a desired constellation rate r in bits/d-dimension, the threshold L can be obtained by counting the constellation points—starting with the ones that have the smallest total cost—until there are 2^{mr} points, and then taking the largest total cost in this collection.

Let M_i^j represent the number of distinct i-vectors $(v_1, v_2, \cdots, v_i) \in \mathscr{Q}^i$ such that their total cost $l_{f(v_1)} + l_{f(v_2)} + \cdots + l_{f(v_i)} = j$. Then M_i^j satisfies the following recursive equation $\forall i \in J_m$:

$$M_i^j = \sum_{k=1}^{n} M_{i-1}^{j-l_k} \tag{3}$$

where $M_i^j = 0$ for $j < 0$ and $M_0^0 = 1$. The M_i^j can hence be determined by evaluating these formulas in increasing order of i. Define C_i^j as the number of i-vectors in $\mathscr{Q}^i$ that have a total cost no greater than j. Clearly, $C_m^j = \sum_{k=1}^{j} M_m^k$. The threshold L is the smallest value of j for which C_m^j is at least 2^{mr}, i.e., $L = \min\{j: C_m^j \geq 2^{mr}\}$.

C. Indexing the Constellation Points

Indexing consists of encoding and decoding the constellation points. There are 2^{mr} points in a constellation (there may be more that satisfy the threshold, but only 2^{mr} are used); hence, each constellation point can be uniquely specified by an mr-bit binary number called the address or the index of the point. In the transmitter, the encoder maps a string of mr bits of data into a unique constellation point. The constellation point is transmitted and received by the receiver where the decoder maps the received point into mr bits of data. The decoder map is the inverse of the of the encoder, and hence any one of these maps specifies the other. It is obvious that when the dimension N is large, the encoder/decoder maps should be such that they can be implemented algorithmically rather than by table look-up. We give here two different algorithms to encode/decode the constellation points. These algorithms are motivated by the indexing algorithm of the scalar-vector quantizer. The first algorithm (Algorithm 1) requires no multiplication, but uses more storage than Algorithm 2 which requires multiplication.

Algorithm 1: We begin by specifying the decoder map and the algorithm that implements it. Following this, the encoding algorithm is presented.

Decoder Map: To each constellation point $z = (z_1, z_2, \cdots, z_m) \in \mathscr{Z}$, assign an m-digit base n number $\mathscr{M}(z) = (f(z_1) - 1, f(z_2) - 1, \cdots, f(z_m) - 1) = \sum_{k=1}^{m} n^{m-k} f(z_k) - 1)$. Clearly, $\mathscr{M}(z_1) = \mathscr{M}(z_2) \Leftrightarrow z_1 = z_2$. All the constellation points are now ordered according to the following two rules: 1) a point z_1 is "smaller than" z_2 (i.e., $z_1 < z_2$) if $T(z_1) < T(z_2)$, where $T(z)$ denotes the total cost of z; and 2) if $T(z_1) = T(z_2)$, then $z_1 < z_2$ if $\mathscr{M}(z_1) < \mathscr{M}(z_2)$. The decoder mapping $E: \mathscr{Z} \rightarrow \{0\} \cup J_{2^{mr}-1}$ is defined as the number of points in $\mathscr{Z}$ that are smaller than the given point, i.e.,

$$\begin{aligned} E(z) &= C_m^{T(z)-1} + \sum_{\substack{w \in \mathscr{Z} \\ T(w) = T(z)}} I_{z,w} \\ &= C_m^{T(z)-1} + \mathscr{E}(z) \end{aligned} \tag{4}$$

where $I_{z,w} = 0$ if $\mathscr{M}(w) \geq \mathscr{M}(z)$; 1 otherwise, and $C_m^0 = 0$. The function $\mathscr{E}(z)$ in the above equation gives the total number of cost $T(z)$ constellation points that are smaller than z. We can further write $\mathscr{E}(z) = \sum_{k=1}^{m} \mathscr{E}_k(z)$, where $\mathscr{E}_k(z)$ is the number of cost $T(z)$ points w such that the base n representations of $\mathscr{M}(z)$ and $\mathscr{M}(w)$ are identical in the $k - 1$ most significant digits, while the kth digit of $\mathscr{M}(w)$ is smaller than that of $\mathscr{M}(z)$. It is simple to see that $\mathscr{E}_k(z) = \sum_{j=1}^{f(z_k)-1} M_{m-k}^{T(z)-L_{k-1}-l_j}$; $k \in J_m$, where $L_0 = 0$ and $L_i = \sum_{j=1}^{i} l_{f(z_j)}$; $i \in J_m$. The decoder function can hence be written as

$$E(z) = C_m^{T(z)-1} + \sum_{k=1}^{m} \sum_{j=1}^{f(z_k)-1} M_{m-k}^{T(z)-L_{k-1}-l_j}. \tag{5}$$

Given that M_i^j and C_m^j; $\forall i \in J_{m-1}$; $\forall j \in J_L$ are computed once [using (3)] and stored in the memory, this equation shows that the total number of additions required (per d-dimension) for the decoding operation is upper bounded by n. It should be noted, though, that each of C_m^j and M_i^j can be up to mr bits long. The number of bit additions is hence bounded by nmr per d-dimension and the memory requirement is bounded by Lm^2r bits.

The decoder map is a slightly modified version of its quantization counterpart described in [7], and ensures that (rule 1) above) the constellation points with the largest total cost are assigned the largest indexes. Hence, of the total number of constellation points (which may be a little more than 2^{mr}), only those 2^{mr} with the smallest cost are transmitted.

Encoder Map: The encoder function $E^{-1}: \{0\} \cup J_{2^{mr}-1} \rightarrow \mathscr{Z}$ is the inverse of the decoder and assigns constellation point to every mr-bit binary address. The encoding can be performed as follows. Given an index c, first compare it with C_m^j; $j \in J_L$ and determine the cost $T(z)$ of the constellation point z corresponding to c. Then let $c' = c - C_m^{T(z)-1}$. The encoding is now done one component at a time starting with z_1. The algorithm is straightforward. Compare c' with the number $M_{m-1}^{T(z)-l_{f(q_1)}}$ of constellation points beginning with q_1 that have cost equal to $T(z)$. If $c' < M_{m-1}^{T(z)-l_{f(q_1)}}$, then $z_1 = q_1$; else, compare $c' - M_{m-1}^{T(z)-l_{f(q_1)}}$ with the number of codevectors $M_{m-1}^{T(z)-l_{f(q_2)}}$ beginning with q_2, and so on, until z_1 is determined. Now, the problem reduces to an equivalent $(m-1)$-component problem which can similarly be handled. This algorithm, when implemented efficiently, requires at most n additions (subtractions) of mr-bit numbers per d-dimension. Its complexity is hence the same as that of the decoder.

The above indexing method requires that a table of $m \times L$ numbers, each up to mr bits long, be stored in the memory. This can be somewhat expensive for practical implementations in voiceband modems. We now present a

divide-and-conquer version of the above algorithm that has a smaller memory requirement.

Algorithm 2: The encoding maps described here assume that m is a power of 2, i.e., $m = 2^K$. They are essentially based on the following idea. A constellation point (which is an m-vector in $\mathscr{C}^m$) is split into two $m/2$-vectors. Assuming that the $m/2$-vectors have been indexed, a two-component version of Algorithm 1 is used to index each vector. The alphabet for each of the two components is the set of $m/2$-vectors. This splitting into two and indexing is repeated until the original constellation point is reduced to the concatenation of pairs of 1-vectors which can be easily indexed using Algorithm 1. As pointed out earlier, this is very similar to the mapping algorithm of Lang and Longstaff [19].

Let $m_i = m/2^{(i-1)}$, $i \in J_{K+1} \equiv \{1, 2, \cdots, K+1\}$. Then $M_{m_i}^j$ is the number of m_i-vectors or m_i-tuples $v \equiv (v_1, v_2, \cdots, v_{m_i}) \in \mathscr{C}^{m_i}$ that have total cost j. Clearly, $M_{m_{(K+1)}}^j = M_1^j$ is the number of elements in the alphabet $\mathscr{C}$ of the SVQ constellation that have a cost equal to j. Also, $C_{m_i}^j$ is the number of m_i-vectors $v \in \mathscr{C}^{m_i}$ with a total cost no greater than j. The encoding and decoding algorithms described below assume that the $M_{m_i}^j$ $\forall i \in \{2, 3, \cdots, K+1\}$, $\forall j \in J_L$ and C_m^j, $\forall j \in J_L$ are computed once using (3) and stored in the memory. This takes up considerably less storage, especially for a large m, than storing the M_k^j for all $k \in J_{m-1}$, as in Algorithm 1. It is further assumed that the alphabet $q_1, q_2, \cdots, q_n$ is indexed such that the corresponding costs $l_1, l_2, \cdots, l_n$ form a nondecreasing sequence, i.e., smaller costs are assigned smaller indexes.

Decoder Map: The mapping given decodes a constellation point (m-vector, $m = 2^K$) by recursively splitting it into two equal parts. Let ${}^i v \equiv (v_1, v_2, \cdots, v_{m_i})$ denote an m_i-vector in $\mathscr{C}^{m_i}$. Also, let ${}^i v_1 \equiv (v_1, v_2, \cdots, v_{m_{(i+1)}})$ and ${}^i v_2 \equiv (v_{(m_{(i+1)}+1)}, v_{(m_{(i+1)}+2)}, \cdots, v_{m_i})$ be the first and the second halves of ${}^i v$, respectively. If $z \equiv (z_1, z_2, \cdots, z_m) \in \mathscr{C}^m$ is the constellation point to be decoded, then let ${}^1 v = z$.

Represent by $E^i: \mathscr{C}^{m_i} \to \{0, 1, 2, \cdots\}$ the decoding function that maps an m_i-vector ${}^i v \in \mathscr{C}^{m_i}$ into a nonnegative integer. Define $E^{K+1}: \mathscr{C} \to \{0, 1, 2, \cdots\}$ as $E^{K+1}(v) = f(v) - 1$, $\forall v \in \mathscr{C}$, where $f(\cdot)$ is the index function in (2).

Assume that all ${}^i v_1$ and ${}^i v_2$ in $\mathscr{C}^{m_{(i+1)}}$ have been indexed using E^{i+1}, i.e., $E^{i+1}({}^i v_1)$ and $E^{i+1}({}^i v_2)$ are the indexes of ${}^i v_1$ and ${}^i v_2$, respectively. Order all m_i-vectors in $\mathscr{C}^{m_i}$ according to the following three rules: 1) a vector ${}^i u \in \mathscr{C}^{m_i}$ is "smaller than" ${}^i w \in \mathscr{C}^{m_i}$ (i.e., ${}^i u < {}^i w$) if $T^i({}^i u) < T^i({}^i w)$, where the function $T^i(\cdot)$ gives the total cost of an m_i-vector $\in \mathscr{C}^{m_i}$; 2) if $T^i({}^i u) = T^i({}^i w)$, then ${}^i u < {}^i w$ if $E^{i+1}({}^i u_1) < E^{i+1}({}^i w_1)$; and 3) if $T^i({}^i u) = T^i({}^i w)$ and $E^{i+1}({}^i u_1) = E^{i+1}({}^i w_1)$, then ${}^i u < {}^i w$ if $E^{i+1}({}^i u_2) < E^{i+1}({}^i w_2)$.

The decoding function $E^i({}^i v)$ is now given as the number of m_i-vectors in $\mathscr{C}^{m_i}$ that are smaller than ${}^i v$. This can be expressed as

$$E^i({}^i v) = \mathscr{E}^i({}^i v) + C_{m_i}^{T^i({}^i v)-1} \tag{6}$$

where $\mathscr{E}^i({}^i v)$ is the number of cost $T^i({}^i v)$ vectors in $\mathscr{C}^{m_i}$ that are smaller than ${}^i v$ and can be computed in terms of pairs of $m_{(i+1)}$-vectors as

$$\mathscr{E}^i({}^i v) = \sum_{k=1}^{T^{i+1}({}^i v_1)-1} M_{m_{(i+1)}}^k M_{m_{(i+1)}}^{T^i({}^i v)-k} + \mathscr{E}^{i+1}({}^i v_1) M_{m_{(i+1)}}^{T^i({}^i v) - T^{(i+1)}({}^i v_1)} + \mathscr{E}^{i+1}({}^i v_2). \tag{7}$$

The first term on the right-hand side of (7) is the number of m_i-vectors with the same cost as ${}^i v$, and whose first halves have cost less than the first half, ${}^i v_1$ of ${}^i v$. The second term is the number of m_i-vectors with the same cost as ${}^i v$, whose first halves have the same cost as ${}^i v_1$, but have index less than that of ${}^i v_1$. These first two terms account for the vectors satisfying ordering rule 2). The third term is the number of m_i-vectors with the same cost as ${}^i v$, with the identical first half, and with a smaller second half. It accounts for vectors satisfying ordering rule 3).

The decoding operation is hence performed by partitioning the input m-tuples into $m/2$ pairs and decoding the pairs using $\mathscr{E}^K(\cdot)$. The pairs are then grouped into 4-tuples and decoded using $\mathscr{E}^{K-1}(\cdot)$, and so on. When $i = 1$ is reached, $E^1(\cdot)$ given by (6) is used for the final decoding step. Note that the $C_{m_i}^j, \forall j \in J_L$ are required only when $i = 1$ in the final decoding step.

The storage requirement of this algorithm is bounded by $Lm(\log m)r$ bits instead of $Lm^2 r$ bits for Algorithm 1. Note that (7) requires multiplications of mr-bit numbers by mr-bit numbers. Taking each such multiplication to consist of $m^2 r^2$ bit multiplications, a simple bound on the computational requirement of the above algorithm is $Lm^2 r^2$ bit operations per d-dimension.

Encoder Map: The encoder mapping is implemented as the inverse of the decoder mapping described above. The aim is to determine the constellation point (m-vector) $z = {}^1 v \in \mathscr{C}^m$ that corresponds to a given mr-bit binary number $E^1({}^1 v)$. This is accomplished by determining $E^2({}^1 v_1)$ and $E^2({}^1 v_2)$ from $E^1({}^1 v)$. The problem now reduces to two problems, each half of the original dimension. These can be similarly handled.

To determine $E^2({}^1 v_1)$ and $E^2({}^1 v_2)$ from $E^1({}^1 v)$, first determine $\mathscr{E}^1({}^1 v)$ and the cost $T^1({}^1 v)$ of ${}^1 v$ using the stored values of C_m^j, $j \in J_L$. The values $T^2({}^1 v_1)$, $\mathscr{E}^2({}^1 v_1)$, $T^2({}^1 v_2)$, and $\mathscr{E}^2({}^1 v_2)$ are next determined from $\mathscr{E}^1({}^1 v)$ by repeated subtraction and a division as explained in the next paragraph.

The first encoding step is to find the cost $T^1({}^1 v)$ of ${}^1 v$. This can be computed as

$$T^1({}^1 v) = \max\{j: C_m^{j-1} \le E^1({}^1 v)\}. \tag{8}$$

Next, the offset can be computed according to (6) as

$$\mathscr{E}^1({}^1 v) = E^1({}^1 v) - C_m^{T^1({}^1 v)-1}. \tag{9}$$

Now, the cost of the first half ${}^1 v_1$ of ${}^1 v$ can be determined from (7) and, consequently, the cost of the second half. The second and third terms on the right-hand side of (7)

count a subset of the m-vectors that have the same total cost as ${}^{1}\boldsymbol{v}$ and the same first half costs. Therefore,

$$M_{m_{(i+1)}}^{T^{i+1}({}^i\boldsymbol{v}_1)} M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-T^{i+1}({}^i\boldsymbol{v}_1)} > \mathscr{E}^{i+1}({}^i\boldsymbol{v}_1) M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-T^{(i+1)}({}^i\boldsymbol{v}_1)} + \mathscr{E}^{i+1}({}^i\boldsymbol{v}_2)$$

and

$$T^{i+1}({}^i\boldsymbol{v}_1) = \max\left\{ j\colon \sum_{k=1}^{j-1} M_{m_{(i+1)}}^{k} M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-k} \le \mathscr{E}^i({}^i\boldsymbol{v}) \right\}. \tag{10}$$

Knowing the first half weight, we can compute the residual term

$$\begin{aligned} \mathscr{D}^i({}^i\boldsymbol{v}) &= \mathscr{E}^i({}^i\boldsymbol{v}) - \sum_{k=1}^{T^{i+1}({}^i\boldsymbol{v}_1)-1} M_{m_{(i+1)}}^{k} M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-k} \\ &= \mathscr{E}^{i+1}({}^i\boldsymbol{v}_1) M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-T^{(i+1)}({}^i\boldsymbol{v}_1)} + \mathscr{E}^{i+1}({}^i\boldsymbol{v}_2). \end{aligned}$$

Finally, the two $\mathscr{E}$'s in $\mathscr{D}$ can be found by observing that

$$0 \le \mathscr{E}^{i+1}({}^i\boldsymbol{v}_2) \le M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-T^{(i+1)}({}^i\boldsymbol{v}_1)} - 1$$

and

$$0 \le \mathscr{E}^{i+1}\left({}^i\boldsymbol{v}_1\right) \le M_{m(i+1)}^{T^{(i+1)}({}^i\boldsymbol{v}_1)}.$$

Thus, according to the Euclidean division algorithm, $\mathscr{E}^{i+1}({}^i\boldsymbol{v}_2)$ is the remainder when $\mathscr{D}^i({}^i\boldsymbol{v})$ is divided by $M_{m_{(i+1)}}^{T^i({}^i\boldsymbol{v})-T^{(i+1)}({}^i\boldsymbol{v}_1)} = M_{m_{(i+1)}}^{T^{(i+1)}({}^i\boldsymbol{v}_2)}$ and $\mathscr{E}^{i+1}({}^i\boldsymbol{v}_1)$ is the quotient.

The halving procedure described above is repeated until m 1-vectors are reached. The complexity of this encoding algorithm is approximately the same as that of the decoding algorithm. The structure of these algorithms makes them amenable to DSP-based implementation.

The indexing scheme described above can easily be adapted to values of m that are not a power of 2. For example, when $m = 12$, a 12-vector can be split into two 6-vectors, and further into four 3-vectors. Each 3-vector can be indexed using Algorithm 1 with $m = 3$.

Table I gives the bounds on computational and storage requirements of both of these algorithms.

TABLE I
COMPUTATIONAL AND STORAGE COMPLEXITIES OF THE TWO INDEXING ALGORITHMS

	SVQ-Constellation		N-Sphere Shaped SVQ-Constellation	
	Computation (bit-operations per d-dimensions)	Storage (bits)	Computation (bit-operations per dimension)	Storage (bits)
Algorithm 1	nmr	Lm^2r	$\frac{N^{3/2}r\, 2^{r+1/2}}{\sqrt{\pi e}}$	$\frac{N^3 r\, 2^{2r-1}}{\pi e}$
Algorithm 2	Lm^2r^2	$Lm(\log m)r$	$\frac{N^3 r^2\, 2^{2r-1}}{\pi e}$	$\frac{N^2(\log N) r\, 2^{2r-1}}{\pi e}$

III. OPTIMAL SHAPING

A. N-Sphere Bounded Constellations

As mentioned before, an N-sphere constellation boundary maximizes the shaping gain in N dimensions. An N-sphere bounded cubic lattice-based constellation can be described as an SVQ constellation with scalar $(d = 1, m = N)$ alphabet $\mathscr{Q} = \{-(n-1)/2, \cdots, -1, 0, 1, \cdots, (n-1)/2\}$ for some large enough odd n, costs $l_i = q_i^2$, and an appropriate L that is determined by the rate r (bits/dimension) of the constellation. Assuming that the continuous approximation holds, L is the squared radius of an N-sphere enclosing 2^{Nr} lattice points and, assuming even N, is given as $L = 2^{2r}(N/2)!^{2/N}/\pi$. Using Sterling's approximation for $(N/2)!$, we get $L \approx 2^{2r}N/(2e\pi)$. Also, for an N-sphere boundary, the size n of the alphabet $\mathscr{Q}$ corresponds to the diameter of the N-sphere and is approximately $2\sqrt{L}$. With this value of L, the computational complexity of Algorithm 1 goes as $N^{3/2}$ and the memory requirement is cubic in N, while for Algorithm 2, the computational complexity is cubic in N and the memory requirement goes as $N^2 \log N$. Hence, for large N, the choice between Algorithms 1 and 2 is dictated by the relative costs of processing and storage. Because of the polynomial dependence of complexity on N, these algorithms can, in principle, be implemented for large N, making it possible to realize a large fraction of the 1.53 dB maximum shaping gain. It should be pointed out, though, that when N is large, any errors caused by channel noise could corrupt the entire data in the block. Table I also gives the bounds on computational and storage requirements of Algorithms 1 and 2 for N-sphere bounded constellations.

Transmission of data using an N-sphere SVQ-shaped cubic lattice-based constellation is shown in Fig. 1 and can be described as follows. The transmitter takes a block of Nr bits from the input data stream and encodes these bits to a constellation point (N-vector) which is transmitted. The encoding can be performed using the encoder map of either Algorithm 1 or 2. At the receiver, the channel output is first quantized, using a bank of N scalar quantizers, to the nearest point on the cubic lattice. This will give back the transmitted constellation point (assuming channel noise does into cause an error) which is converted to an Nr-bit block using the corresponding decoder map.

B. Shaping and Constellation Expansion Ratio

While N-sphere shaping achieves the best shaping gains, it also results in large CER_2 and PAR_2. Table II gives the shaping gain γ_s, CER_2, and PAR_2 of N-spheres for various N (also see [8]). For large N, the probability of occurrence of the points in the constituent 2D constellation is not uniform, but is close to a two-dimensional Gaussian distribution even when the N-dimensional constellation points themselves are equally probable. Channel capacity arguments for the additive Gaussian noise channel also show that the optimal distribution of points in the constituent 2D constellation is the two-dimensional Gaussian distribution. Because of this, the points of the

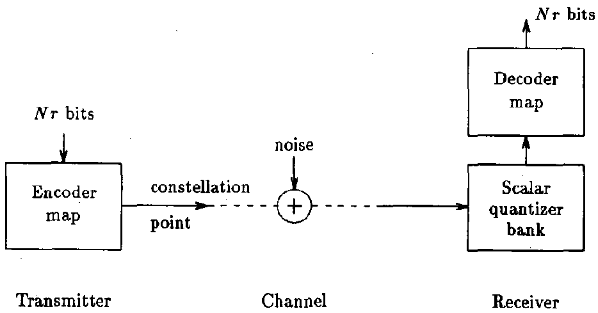

Fig. 1. Transmitter/receiver structure for an SVQ-shaped cubic lattice-based constellation.

TABLE II
SHAPING GAINS γ_s, CER_2, AND PAR_2 OF N-SPHERES

N	γ_s (dB)	CER_2	PAR_2
2	0.2	1.0	2.0
4	0.46	1.41	3.0
8	0.73	2.21	5.0
16	0.98	3.76	9.0
32	1.17	6.80	17.0
64	1.31	12.79	33.0

constituent 2D constellation that occur most frequently are the ones that are closet to the origin; hence, the average energy per two dimensions of this constellation is small, and this is the reason for its large shaping gain. On the other hand, the points on the periphery of the constituent 2D constellation are very improbable, suggesting that even if these points are removed, resulting in a smaller CER_2, good shaping gains should still be possible. Bounds on the shaping gain for a given CER_2 and PAR_2 derived in [8] (see Figs. 2 and 3 of this paper) show that it is indeed possible to get large shaping gains at considerably smaller values of CER_2 and PAR_2 than those required for N-spheres. Soon it will be shown that these bounds can indeed be achieved asymptotically in N by SVQ shaping.

A subtle point worth observing is the following. The definition of the constituent 2D constellation given in [8] (and in Section I) is a little too restrictive. For a QAM modem-based implementation, all that is really required is that the N dimensions be partitioned into a set of $N/2$ pairs of dimensions, and the constituent constellation along any pair in this set, if they are all the same (if not, take the largest of such constituent constellations), can be taken as the constituent 2D constellation. This is less restrictive than requiring that the constituent 2D constellation be the same for all possible pairs of dimensions. Although it is not mentioned, the bounds on shaping gain derived in [8] are asymptotically achievable only for a constraint on the expansion ratio CER_2 of this less restrictive definition of the constituent 2D constellation. For the rest of this paper, we use these new definitions of the constituent 2D constellation C_2 and the constellation expansion ratio CER_2.

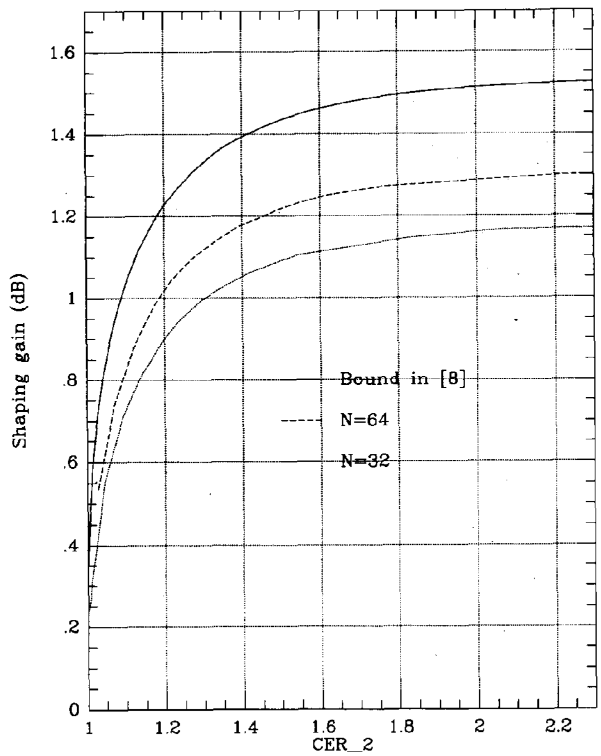

Fig. 2. Shaping gain γ_s as a function of CER_2 for SVQ shaping.

To demonstrate that optimal SVQ shaping is possible for a given constraint on CER_2, we first consider the simpler problem of optimal SVQ shaping for a given CER_1, which is the constellation expansion ratio of the constituent 1D constellation C_1. The constituent 1D constellation is defined as the largest of the constituent constellations along each dimension. This will be generalized to the 2D case.

C. Optimal Shaping for a Given CER_1

The problem is to determine the shaping region of a rate r (bits per dimension) N-dimensional cubic lattice-based constellation that maximizes the shaping gain for $1 \leq CER_1 \leq \beta$. For this rate, the baseline constellation is bounded by an N-cube of side $(2^r - 1)$ and has 2^r points in its constituent 1D constellation. The desired constellation has at most $n = \beta 2^r$ points in its constituent 1D constellation, and is a subset of points inside on outer N-cube of side $\beta(2^r - 1)$. It is obvious that the best way to choose a given small number of points inside the outer N-cube while minimizing the average energy is to choose them inside an N-sphere of appropriate radius centered at the origin. As the number of points to be chosen increases, the radius of the N-sphere that contains them also increases until the sphere begins to intersect with the outer N-cube. When that happens, only the points that lie in the intersection of the N-sphere interior and the N-cube

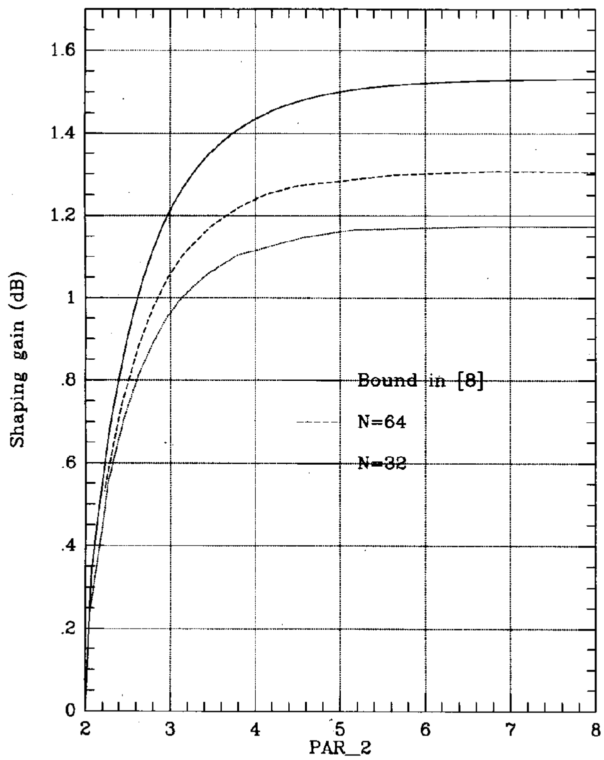

Fig. 3. Shaping gain γ_s as a function of PAR_2 for SVQ shaping.

TABLE III
THE SHAPING GAIN Γ_S FOR A GIVEN CER_1. THE CORRESPONDING VALUES OF PAR_1, CER_2, AND PAR_2 ARE ALSO GIVEN

γ_s (dB)	CER_1	PAR_1	CER_2	PAR_2
$N = 32$				
0.00	1.00	3.00	1.00	3.00
0.69	1.06	3.95	1.12	3.95
0.79	1.08	4.22	1.17	4.22
0.86	1.11	4.48	1.23	4.48
0.97	1.16	5.02	1.35	5.02
1.08	1.26	6.13	1.59	6.13
1.15	1.50	8.81	2.25	8.81
1.17	2.01	16.81	4.04	16.81
1.17	2.47	24.10	6.10	24.10
$N = 64$				
0.00	1.00	3.00	1.00	3.00
1.04	1.12	4.83	1.26	4.83
1.09	1.15	5.09	1.32	5.09
1.17	1.20	5.67	1.44	5.67
1.24	1.29	6.67	1.66	6.67
1.27	1.39	7.76	1.93	7.76
1.29	1.50	9.12	2.25	9.12
1.30	1.65	11.08	2.72	11.08
1.30	1.74	12.24	3.03	12.24
1.30	2.01	16.35	4.04	16.35
1.30	2.47	24.70	6.10	24.70

interior must be included in the collection. The size of the N-sphere can be increased if necessary to accommodate a total of 2^{Nr} points in the required constellation. This procedure of choosing the constellation points ensures that the points closest to the origin (minimum energy) that satisfy the outer N-cube constraint are chosen first. Hence, the resulting constellation has the smallest possible average power for the required number of points. The shaping region of this constellation will be the intersection of an N-sphere interior and an N-cube interior. It might happen that for a small N (and large β), the N-sphere is entirely contained inside the N-cube. The resulting constellation then is bounded by the N-sphere and actually $CER_1 \leq \beta$; equality holds only if the diameter of the N-sphere is equal to the side of the N-cube. As in [8], it can be reasoned that the above constellations also give the best tradeoff between the shaping gain γ_s and the PAR_1.

The optimal constellation described above can be specified as an N-dimensional SVQ constellation ($d = 1$ and $m = N$) with $\mathscr{C} = \{-(n-1)/2, \cdots, -1, 0, 1, \cdots, (n-1)/2\}$ (assuming odd n), $l_i = q_i^2$, and L chosen such that the constellation has (at least) 2^{Nr} points. The indexing algorithms described in the previous section can therefore be used to encode/decode the constellation points. The transmitter/receiver block diagram in this case is also described by Fig. 1.

Table III gives the shaping gain γ_s for various values of CER_1 (and the corresponding PAR_1) for two different N. For a given $CER_1 = \beta$ of the constituent 1D constellation, CER_2 is upper bounded by β^2 and PAR_2 is upper bounded by PAR_1 (for large N, these quantities become equal to their bound). Table III also gives these (upper-bounds) values for the corresponding constituent 2D constellation. For these values of CER_2 and PAR_2, however, higher shaping gains are possible, as shown next.

D. Optimal Shaping for a Given CER_2

The optimal shaping solution in this case is the generalization of the 1D solution described above. It is shown in [8] (also see [20], [22]) that the required optimally shaped N-dimensional constellation—under the $CER_2 \leq \beta$ constraint—should have a circular constituent 2D constellation $\mathscr{C}$ with $n = \beta 2^r$ smallest energy points on the 2D cubic lattice, where r is the rate in bits/d-dimensions and $d = 2$. The required constellation is hence constrained to be a subset of points enclosed by $\mathscr{C}^m$ (where $m = N/2$), which is the m-fold Cartesian product of $\mathscr{C}$ with itself. Proceeding as in the 1D case, we choose the points in the intersection of the interiors of C^m and an N-sphere of appropriate radius so that the constellation has 2^{mr} points. This ensures that we choose the 2^{mr} minimum energy points that satisfy the CER_2 constraint (i.e., lie inside $\mathscr{C}^m$). Hence, the average power of this constellation is the minimum for the given size. This constellation can also be

described as an SVQ constellation. The alphabet $\mathscr{Q} \equiv \{q_1, q_2, \cdots, q_n\}$ consists of the $n = \beta 2^r$ points of the constituent 2D constellation $\mathscr{C}$. The cost l_i associated with q_i is its squared distance from the origin, i.e., l_i is the energy of q_i. The threshold L is once again chosen such that the constellation consists of (at least) 2^{mr} points. As shown in [8], this optimally shaped constellation under the CER_2 constraint also represents the best tradeoff between shaping gain and PAR_2. A generalization of the above method to optimal shaping for a given CER_j, $j > 2$ is straightforward.

Table IV gives the optimal γ_s for various values of CER_2 and the corresponding PAR_2. These results are also plotted in Figs. 2 and 3, along with the asymptotic bounds for large N, and demonstrate that large shaping gains are indeed possible with a small CER_2.

So far, we have described the optimal constellations for a given CER and PAR and presented two algorithms to index the constellation points. Although the complexity of these algorithms is polynomial in the constellation dimension N, it is exponential in its rate r. This makes it difficult to realize a large shaping gain at high rates. In the next section, we show that at high rates, it is possible to implement an approximation of the optimal constellation such that the indexing complexity becomes independent of the data rate with negligible effect on the shaping gain. This is accomplished by using results on nonequiprobable signaling [11].

TABLE IV
THE SHAPING GAIN Γ_S FOR A GIVEN CER_2. THE CORRESPONDING VALUE OF PAR_2 IS ALSO GIVEN

γ_s (dB)	CER_2	PAR_2
$N = 32$		
0.00	1.00	2.00
0.54	1.05	2.27
0.80	1.14	2.62
0.94	1.24	2.95
1.02	1.36	3.28
1.09	1.54	3.79
1.13	1.75	4.34
1.15	1.99	4.96
1.17	2.47	6.17
1.17	3.06	7.67
$N = 64$		
0.00	1.00	2.00
0.64	1.05	2.33
0.81	1.10	2.53
0.92	1.14	2.71
1.06	1.24	3.04
1.22	1.51	3.82
1.29	2.01	5.16
1.30	2.53	6.52
1.30	2.99	7.72

IV. Shaping at High Rates

Calderbank and Ozarow in [11] have shown that it is, in principle, possible to achieve most of the maximum shaping gain of 1.53 dB by partitioning a circular 2D constellation (with a large number of points) into a small number t of equal area regions (circular shells) and using all the constellation points in a region with the same probability. Virtually all of the shaping gain can be achieved with just $t = 16$ regions and a CER_2 less than about 2. For $t = 8$, a shaping gain of over 1.4 dB can be realized. The shaping gain versus PAR_2 plot for $t = 32$ given in [11, Fig. 4(e)] (the notation in [11] is different from that used here) is claimed to be indistinguishable from the optimal shaping gain versus PAR_2 plot in [8].

These results suggest that at high rates, there is almost no loss in shaping gain if the optimal constellation described in Section III-D is approximated by the following constellation. Partition the given circular constituent 2D constellation into a maximum of $t = 16$ regions (circular shells), each containing the same number of points. To all the points within a given region, assign a cost equal to the average energy of that region. This ensures that all points in the same region of the constituent 2D constellation occur with the same frequency in the multidimensional constellation. Since SVQ shaping can minimize the average constellation energy (cost) subject to the above constraint, for a given t it can asymptotically (in dimension) achieve the performance described in [11]. The shaping gain for a given t is independent of the number of points in the constituent 2D constellation assuming a large number of points. Therefore, the complexity of this SVQ shaping scheme for nearly optimal shaping does not continue to increase with the constellation rate r. An example is presented in the next section. Numerical results show that for r greater than about 6 bits/2D, the complexity can be made independent of the rate with little or no effect on the shaping gain.

The above reduction in complexity makes it possible to achieve a large shaping gain, even for high-rate constellations. In the next section, we consider an example that demonstrates this.

V. Example of an SVQ-Shaped Constellation

Assume that it is desired to transmit binary data using a 64-dimensional SVQ-shaped uncoded Z^{64}-based constellation at the rate of 8 bits/2D. (Trellis-coded constellations are considered later.) The constituent 2D constellation in this case must consist of at least 256 points. A circular 256-point 2D constellation, however, results in only 0.2 dB shaping gain (that of a circle over a square). To achieve higher shaping gains, the constituent 2D constellatin must be expanded to have more than 256 points. In this example, we assume that a shaping CER_2 of 1.5 (corresponding to a 384-point 2D constellation) is acceptable. The 2D constellation A_0 hence consists of 384 points on the translated lattice $Z^2 + (1/2, 1/2)$ that are enclosed inside a circle of appropriate radius. The circular constellation A_0 is partitioned into $t = 12$ regions

$R_1, R_2, \cdots, R_{12}$, each containing 32 points. The region R_1 consists of the 32 lowest energy (smallest squared distance from the origin) points in A_0, R_2 consists of the 32 next higher energy points in A_0, and so on. There are many different ways to choose the regions $R_1, R_2, \cdots, R_{12}$: however, one that preserves the $\pi/2$ rotational symmetry of A_0 is preferable [8].

As described in the previous section, close to optimal shaping gain can be achieved by using all 32 points in any given region R_i, $i \in J_{12} \equiv \{1, 2, \cdots, 12\}$ with the same probability. In the context of SVQ shaping, this can be accomplished by taking the 2D alphabet ($d = 2$) of the SVQ constellation as the 384 points in A_0 and assigning the same cost to all points in the same region. The threshold L can be determined such that the constellation has $2^{32 \times 8} = 2^{256}$ points. Alternatively, for a more efficient implementation, we define a *region constellation* where the alphabet is taken as the 12 ($n = t = 12$) regions, i.e., $\mathscr{Q} \equiv \mathscr{R} = \{R_1, R_2, \cdots, R_{12}\}$, and every region R_i, $i \in J_{12}$ is assigned a cost $l_i = i$. The justification for this cost assignment is that for a large number of points in each region, the average cost of the region is approximately proportional to the region number. Since each *region vector* represents $(2^5)^{32} = 2^{160}$ constellation points and there are 2^{256} constellation points, the region constellation must consist of $2^{256}/2^{160} = 2^{96}$ region vectors in $\mathscr{R}^{32}$. The threshold L is selected so that the region constellation contains this many points.

The transmitter in a QAM-based system accepts binary data in blocks of $32 \times 8 = 256$ bits and transmits each block using 32 2D-points (equivalent to one point on the 64-dimensional constellation). Out of the 256 bits in each block, the encoder maps 96 bits into a region vector in $\mathscr{R}^{32}$. These 96 bits are called the *shaped bits*. The additional 5 bits/2D (a total of 160 bits) are used to determine which point ($\in A_0$) of each 32-point region is transmitted. These 160 bits are called the *unshaped bits*. In the receiver, the unshaped bits (5 bits/2D) are recovered by determining which point within each region was received, and the 96 shaped bits are recovered by using the decoder map on the received region vector. Fig. 4 shows a block diagram of the transmission system described above.

Numerical evaluation shows that the above SVQ-shaped constellation achieves a shaping gain of 1.20 dB and has a $\mathrm{PAR}_2 = 3.76$. If Algorithm 2 is used to index the constellation points, the encoding and decoding operations each require a peak computational load of about 60 multiply–adds/2D (assuming a 16 bit processor) and 3 kbytes of memory.

The complexity of the shaping scheme using Algorithm 2 in the example above can be further reduced with little or no effect on the shaping gain. This is done by repeatedly applying the ideas of Section IV to constituent constellations in 4, 8, 16, and 32 dimensions. For instance, the number M_8^j is the total number of cost $T^3({}^3v) = j$ points ($K = 5$ and ${}^3v$ represents an 8-tuple in $\mathscr{Q}^8$) in the constituent 16-dimensional constellation. The constituent 16-dimensional constellation can be divided into regions of, say, 1024 points each. The 1024 points with the smallest costs belong to the first region, the 1024 points with the next higher costs belong to the next region, and so on. All points in the same region are now assigned the same cost (this may be different from the original cost of the points). This corresponds to modifying the numbers M_8^j, $j = 1, 2, 3, \cdots$ to a new set $\mathscr{M}_8^j$, where $\mathscr{M}_8^j$ is the new number of points in the constituent 16-dimensional constellation with the modified cost $\mathscr{T}^3(v) = j$. Also, let $\mathscr{C}_8^j$ be the (new) number of points in the 16-dimensional constellation with (modified) cost $\mathscr{T}^3({}^3v) \le j$.

The index $E^3({}^3v)$ of ${}^3v$ can now be used to determine $\mathscr{T}^3({}^3v)$ and $e^3({}^3v)$—*which is the number of (modified) cost* $\mathscr{T}^3({}^3v)$ *points in the constituent* 16-*dimensional constellation that are smaller than* ${}^3v$.

For this approach, the encoding function of Algorithm 2 is modified as follows:

$$E^i({}^iv) = \mathscr{E}^i({}^iv) + C_{m_i}^{T^i({}^iv)-1} \tag{11}$$

where

$$\mathscr{E}^i({}^iv) = \sum_{k=1}^{\mathscr{T}^i({}^iv_1)-1} \mathscr{M}_{m_{(i+1)}}^k \mathscr{M}_{m_{(i+1)}}^{T^i({}^iv)-k} + e^{i+1}({}^iv_1)\mathscr{M}_{m_{(i+1)}}^{T^i({}^iv)-\mathscr{T}^{(i+1)}({}^iv_1)} + e^{i+1}({}^iv_2) \tag{12}$$

with

$$M_{m_i}^j = \sum_{k=1}^{j-1} \mathscr{M}_{m_{(i+1)}}^{j-k} \mathscr{M}_{m_{(i+1)}}^k \tag{13}$$

$$C_{m_i}^j = \sum_{k=1}^{j} M_{m_i}^k \tag{14}$$

and

$$T^i({}^iv) = \mathscr{T}^{i+1}({}^iv_1) + \mathscr{T}^{i+1}({}^iv_2). \tag{15}$$

With this modification, a variety of tradeoffs among shaping gain, computational complexity, and storage requirement are possible. In the above example, a shaping gain of about 1.15 dB can be realized at a PAR_2 of 3.75 with a worst case computational complexity of about 45 multiply–adds/2D (assuming a 16 bit processor) and a storage requirement of around 1.5 kbytes.

VI. Compatibility with Trellis Coding

We have so far discussed the optimal shaping of cubic lattice-based N-dimensional constellations. These constellations have a large shaping gain, but offer no coding gain. Since maximum achievable coding gains (up to about 6 dB) are significantly larger than the maximum shaping gain of 1.53 dB, the present approach will be useful only if it allows constellations based on trellis codes that coding gains over the cubic lattice. We now describe how SVQ shaping can be implemented on trellis-coded constellations. In fact, the SVQ-shaped trellis-coded constellation is the transmission dual of the trellis-based scalar-vector quantizer described in [5].

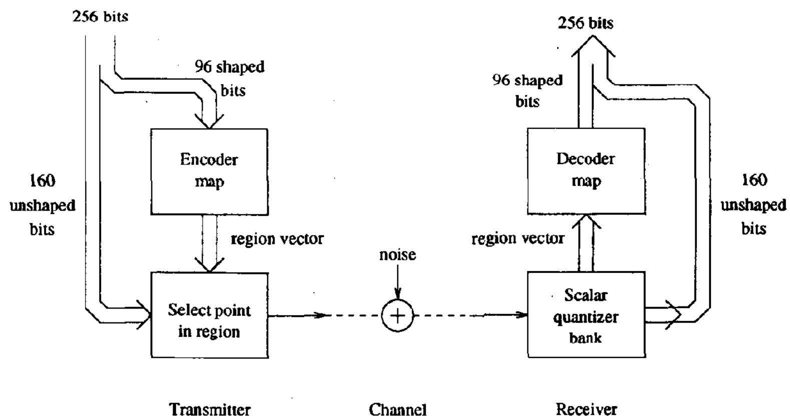

Fig. 4. Transmitter/receiver structure for the example in Section V.

It was shown in [2] that trellis codes can be constructed from a redundant cubic lattice (that has a higher density of points than required) to achieve significant coding gains. Most of the useful trellis codes belong to the class of coset codes [3]. A d_c-dimensional binary trellis code is constructed by partitioning a d_c-dimensional binary lattice Λ into $\nu = 2^{k+1}$ cosets of a sublattice Λ', which we call the coset lattice. A rate $k/(k+1)$ convolutional code G_c is used to specify the coset. Since many good codes can be constructed from redundant cubic lattices, we shall assume here that both Λ and Λ' are cubic lattices. The k input bits to the convolutional encoder produce $k+1$ output bits, called the *coded bits*, which select one of the ν cosets of Λ'. The remaining input bits, called the *uncoded bits*, select a point within the coset lattice Λ'.

Shaping of trellis-coded constellations can be easily accomplished by requiring that each coset of Λ' (in Λ) have the same cost (energy) profile, i.e., by requiring that all points of a given cost in Λ must be distributed equally between the ν costs. If this requirement is satisfied, we can form ν-tuples of equal cost points such that each ν-tuple contains exactly one point from each of the ν cosets. Shaping is now performed only on the uncoded bits or, equivalently, only on the coset lattice Λ'. The output of the shaping encoder is a block of m points in Λ'. Each point in Λ' specifies a unique ν-tuple. The $k+1$ coded bits (per d_c dimensions) at the output of the conventional encoder G_c are only used to select one of the points in this ν-tuple.

In QAM transmission, the lattice (translate) Λ is usually $\mathbf{Z}^2 + (1/2, 1/2)$. This could, for example, be partitioned into four cosets of $2\mathbf{Z}^2 + (1/2, 1/2)$ which are selected using a rate $1/2$ convolutional coder. In this case, it is easy to check that the four cosets have identical energy profiles. This is because 0°, 90°, 180°, and 270° rotation of every point in $2\mathbf{Z}^2 + (1/2, 1/2)$ generates a 4-tuple of equal energy points, each in a different coset. Hence, if every point is assigned a cost equal to its energy, any trellis code based on this partition satisfies the requirement above. In general, 2D trellis code based on this partition satisfies the requirement above. In general, 2D trellis codes that partition $\mathbf{Z}^2 + (1/2, 1/2)$ into eight or more cosets may not automatically satisfy this requirement if points are assigned a cost equal to their energy. In this case, the costs should be modified to comply with the requirement. For high rate constellations, this does not lead to any significant loss in shaping gain.[1]

Fig. 5 gives a block diagram of a QAM transmission system that uses an N-dimensional ($N = 2m$) SVQ-shaped trellis-coded constellation of rate r bits/2D. The trellis code is assumed to be 2D ($d_c = 2$) based on a rate $1/2$ ($k = 1$) convolutional code G_c and a partition of the 2D cubic lattice (translate) $\Lambda = \mathbf{Z}^2 + (1/2, 1/2)$ into four cosets of $\Lambda' = 2\mathbf{Z}^2 + (1/2, 1/2)$. As mentioned above, the encoder shapes only the cubic coset lattice (translate) Λ' using the $m(r-1)$ uncoded bits. This can be done by using the encoder described in Fig. 1. The output of the shaping operation is a block of m points in Λ'. Each point in Λ' specifies a unique 4-tuple ($\nu = 4$) containing exactly one point from each coset of Λ'. The $m \times 1$ input bits to the convolutional encoder produce $m \times 2$ coded bits which are used to convert the block of m points in Λ' to a trellis code sequence. In the receiver, a Viterbi decoder is used to map the received sequence to the nearest trellis code sequence. The received sequence is partitioned into blocks of m points, each in Λ. Assuming that no channel errors occurred, the coset information is used to recover $m \times 1$ bits using G_c^{-1}, and the block of received points in Λ is converted to points in Λ'. Now, the decoder of Fig. 1 is used to recover the remaining $m(r-1)$ information bits.

As another example, we will now describe how SVQ shaping on regions as explained in Section V can be used with trellis channel coding. Suppose shaping is performed on frames consisting of m 2D-symbols. Each frame, the

[1] For low rate constellations, this could lead to some loss in shaping gain. In this case, the indexing algorithm similar to that of the trellis-based scalar-vector quantizer [5] can be used. This algorithm avoids the above requirement, and hence does not result in any loss in shaping gain, even for low rate constellations.

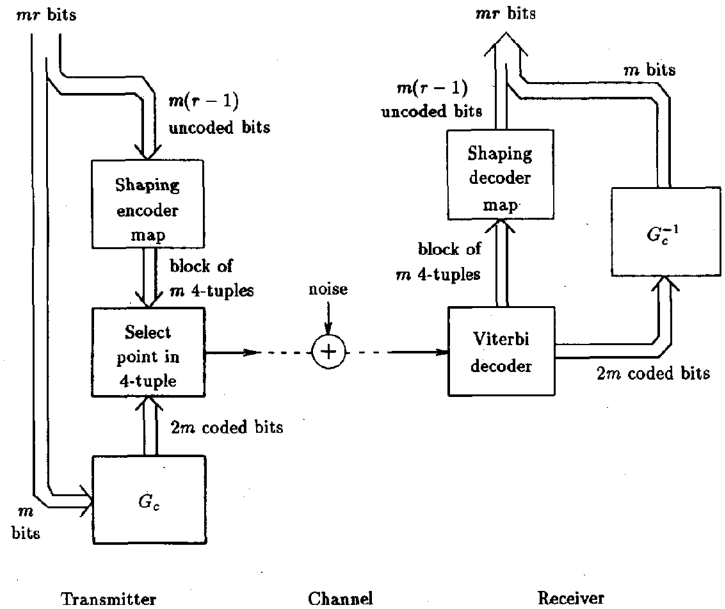

Fig. 5. Transmitter/receiver structure for an SVQ-shaped trellis-coded constellation.

shaping encoder accepts n_s shaping bits and maps them into one of 2^{n_s} region vectors. The channel trellis encoder accepts k_c bits per 2D symbol and generates a sequence of 2D subsets. The 2D regions must be selected so that each region contains the same number of points, and there are an equal number, 2^{n_u}, of points from each coding subset in each region. The transmitter accepts n_u uncoded bits per 2D symbol, which are used to select a unique 2D point from the ring specified by the corresponding component of the region vector and subset specified by the channel trellis encoder. The resulting sequences are paths in the trellis of the channel trellis encoder.

If the Viterbi decoder makes an error due to channel noise, the recovered data bits will be corrupted. In general, it is not possible for the decoder to conclude if an error has occurred. However, in the above scheme, there is one type of error that is easily detectable. It corresponds to the case when the received block of m points at the output of the Viterbi decoder has a total cost greater than the threshold L. This is called a constellation overload error. Clearly, this can only be the result of a channel error. This kind of error is most likely to result from the outermost points in the shaping region. A simple way to deal with it is to let it cause bit errors. Often, the knowledge that an error has occurred is useful even if the error cannot be corrected. A better but computationally more expensive way to deal with overload errors is to use a search algorithm that maps the received channel output sequence to the closest "allowed" (within the shaping region) trellis sequence rather than the closest trellis sequence. For this purpose, an algorithm similar to the codebook search algorithm of the trellis-based scalar-vector qantizer [5] can be used in place of the simpler Viterbi trellis decoder. While this does not guarantee error-free decoding, it reduces the probability of such errors. This gain is the result of the fact that the outermost constellation points in the shaping region have fewer neighbors than the inside points. For Voronoi constellations, such errors are not easy to detect, and hence no such error correction possibility exists.

VII. Comparisons with Trellis Shaping

Trellis shaping was introduced by Forney in [10] and uses the "Voronoi region" of a trellis code to shape the constellation. It can realize large shaping gains—1.36 dB with a 256-state trellis. By incorporating peak constraints, peak signal power can be significantly reduced to make trellis shaping useful in practice. Since trellis shaping has been implemented in commercial modems and is a practical alternative to SVQ shaping, we will now compare them.

Trellis shaping based on Ungerboeck's four-state 2D code is simple to implement and results in about 1 dB shaping gain. With peak constraints, the corresponding PAR_2 is 3.75 and the CER_2 is about 1.5. The same shaping gain can also be obtained using 16-dimensional SVQ shaping, which is also simple to implement and results in similar PAR_2 and CER_2 but smaller encoding delay (only 8 QAM symbols rather than about 20 for trellis shaping). On the other hand, 1 dB shaping gain can be obtained using 32-dimensional SVQ shaping with a PAR_2 of only 3.2, and also using 64-dimensional shaping with a PAR_2 of only 2.9. This is even smaller than the $PAR_2 = 3$ of the baseline unshaped constellation. Such small values of PAR_2 are useful for transmission over

most real-world channels because they introduce harmonic distortion at high signal levels. For trellis shaping (with 1 dB shaping gain), the PAR_2 cannot be reduced below 3.75. Also, trellis shaping requires constellation switching to support a noninteger bit rate per symbol, whereas SVQ shaping can naturally support noninteger rates.

It seems that shaping gains higher than 1 dB are more easily attainable with SVQ shaping than trellis shaping. In general, for a given PAR_2 or CER_2, no other shaping scheme results in a higher shaping gain and smaller delay than the one described in this paper.

In this paper, we have implicitly assumed that the channel over which the constellation points are transmitted is a memoryless channel corrupted by white Gaussian noise. In practice, there are important channels which are not memoryless, but suffer from intersymbol interference. Until recently, trellis shaping had an edge over other shaping methods because it was the only scheme that could be combined with an equalization technique called precoding—resulting in trellis precoding—to realize shaping gains over intersymbol interference (ISI) channels [17]. But a newly disclosed precoder [23]–[25] decouples shaping and equalization and enables the use of SVQ shaping (or any other method of shaping) for transmission over ISI channels. The ITU–TSS committee formulating the V.fast modem standard was considering including trellis precoding, but has now agreed to use shell mapping (SVQ shaping) and a precoder similar to [23].

VIII. Conclusions

We have described a new shaping scheme called SVQ shaping. SVQ shaping is motivated by a type of structured vector quantizer called the scalar-vector quantizer. Optimal (N-sphere) SVQ shaping can realize a large fraction of the maximum shaping gain of 1.53 dB. Its implementation complexity is polynomial in the constellation dimension N and (at high rates) is independent of the constellation rate. Although their shaping gain approaches 1.53 dB as $N \to \infty$, N-sphere bounded constellations result in a large CER_2 and PAR_2, and are therefore not suitable for transmission over QAM channels. It is shown that SVQ shaping can achieve the maximum shaping gain for a given CER_2 (or PAR_2) and constellation dimension. This is useful because even a small constellation expansion can result in relatively large shaping gains.

SVQ shaping offers a better PAR_2/shaping gain/delay tradeoff than trellis shaping (even with peak constraints), is simple to implement, and can support noninteger data rates without constellation switching. This makes it a superior alternative to trellis shaping.

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EXHIBIT L

Amendment

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT:	Long, Guozhu	EXAMINER:	Tse, Y.
SERIAL NO.:	08/097,343	GROUP:	2614
FILED:	07/23/93	CASE NO.:	CX092016
ENTITLED:	DEVICE AND METHOD FOR UTILIZING ZERO-PADDING CONSTELLATION SWITCHING WITH FRAME MAPPING		

Motorola, Inc.
Corporate Offices
1303 E. Algonquin Road
Schaumburg, IL 60196
February 1, 1995

SUPPLEMENTARY AMENDMENT AND RESPONSE UNDER 37 CFR 1.115

Honorable Commissioner of
Patents and Trademarks
Washington, D.C. 20231

Sir:

In response to a conference with Examiner Young Tse on 1/26/95, the Applicant hereby respectfully submit the following Supplementary Amendment and Response:

SUPPLEMENTARY AMENDMENT

<u>In the Claims:</u>

Please amend claims 5-8 to read as follows:

5. (Amended) A frame-mapping method for mapping successive frames of data to groups of N symbols, N a predetermined integer (N>1), such that, on average, a fractional number Q of bits are mappable per frame without constellation switching, comprising the steps of:

A) selecting a number of bits for each frame to be one of: J-1, J, where J is an integer such that J -1< Q < J, according to a predetermined pattern,

B) in frames of J-1 bits, inserting a zero in a most significant bit (MSB) position,

C) selecting a [signal constellation with] <u>set of</u> 2^J possible <u>combinations of N symbols, where each symbol is chosen from a signal constellation</u> [signal points each representing a possible group of N symbols], and

D) mapping the frame bits such that for MSB = 0, one of the 2^{J-1} [signal points] <u>possible combinations of N symbols</u> of least average energy is selected from the [signal constellation] <u>set of 2^J possible combinations</u>.

6. (Amended) The frame-mapping method of claim 5 wherein :

A) the frame-mapping method is shell mapping,

[B) the signal constellation is a subset of the N-fold Cartesian product of a second signal constellation,]

<u>B</u>[C]) ~~the~~ [second] signal constellation is divided into M equal size rings, <u>M an integer,</u> each of which has 2^v (v>0 a predetermined integer) points, and

<u>C</u>[D]) where in frames of J-1 bits, K-1 (K = J-N·v) bits, together with a zero as the MSB, are utilized for shell mapping, to obtain N ring indices ranging from 0 to M-1 such that an average sum of N ring indices obtained in shell mapping is kept small, thereby keeping the average signal power small, and

<u>D</u>[E]) where in frames of J bits, K bits are utilized for shell mapping to obtain N ring indices.

7. (Amended) A frame-mapping device for mapping successive frames of data to groups of N symbols, N a predetermined integer (N>1), such that, on

average, a fractional number Q of bits are mappable per frame without constellation switching, comprising:

A) a frame selector, operably coupled to receive the data, for selecting a number of bits for each frame of data to be one of: J-1, J, where J is an integer such that J -1< Q < J, according to a predetermined pattern,

B) a zero insertion unit, operably coupled to the frame selector, for, in frames of J-1 bits, inserting a zero in a most significant bit (MSB) position,

C) a signal constellation selector/mapper, operably coupled to the zero insertion unit, for selecting a [signal constellation with] set of 2^J possible combinations of N symbols, where each symbol is chosen from a signal constellation [signal points each representing a possible group of N symbols], and mapping the frame bits such that for MSB = 0, one of 2^{J-1} [signal points] possible combinations of N symbols of least average energy is selected from the [signal constellation] set of 2^J possible combinations.

8. (Amended) The frame-mapping device of claim 7 wherein:

A) the frame-mapping device is a shell mapper,

[B) the signal constellation is a subset of an N-fold Cartesian product of a second signal constellation,]

B[C]) the number of bits in each frame is one of: J-1 and J,

C[D]) where in frames of J-1 bits, K-1 (K = J-N•v) bits, together with a zero as the MSB, are utilized for shell mapping to obtain N ring indices ranging from 0 to M-1 (M being an integer) such that an average sum of N ring indices obtained in shell mapping is minimized, thereby minimizing an average signal power, and

D[E]) where in frames having a total of J bits, K bits are utilized for shell mapping to obtain N ring indices.

REMARKS

26

In the phone conference with Examiner Tse on 1/26/95, the Examiner submitted:

1) The equations on line 27 of page 10 and line 13 of page 11 were unclear since each equation had a same symbol on both sides of the equals sign and further terms on one side only, a terminology that he submitted is inaccurate. It was explained that the terminology for the equations on line 27 of page 10 and line 13 of page 11 is terminology specific to computer software technology and is known to those skilled in the art. For example, this terminology is utilized in determining a radix-2 decimation-in-time FFT, as is set forth in Chart 1 page 28-24 of the <u>REFERENCE DATA FOR ENGINEERS: Radio, Electronics, Computer & Communications</u>, 8th Edition, SAMS Prentice Hall Computer Publishing, 1993. A copy of pages 28-22 through 28-25 of said reference are included herewith for the Examiner's convenience. Note that in Chart 1 :

j = j - n1
n1 = n1/2
j = j + n1
etc.

Thus, the terminology of the equations on line 27 of page 10 and line 13 of page 11 is believed to be clear to those skilled in the art.

Since the Examiner objected to the terminology of 6B and 8B, the Applicant has deleted the terminology "the signal constellation is a subset of the N-fold Cartesian product of a second signal constellation" of claims 6B and 8B, and has amended claims 5 and 7 for clarification.

Thus, since the Examiner submitted that claims 1-4 were in condition for allowance, and the Applicant has amended claims 5-8 to eliminate the terminology objected to by the Examiner, Applicant respectfully submits that claims 1-8 are now in a form for allowance.

Allowance of the specification and claims 1-8 is hereby

respectfully requested.

Respectfully submitted,

Guozhu Long

By Darleen J. Stockley

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EXHIBIT M

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NO.
08/097,343	07/23/93	LONG G	CX092016

TSE, Y EXAMINER

26M1/0203

DONALD B. SOUTHARD
MOTOROLA, INC.
1303 E. ALGONQUIN RD.
SCHAUMBURG, IL 60196

ART UNIT	PAPER NUMBER
2614	8

DATE MAILED: 02/03/95

NOTICE OF ALLOWABILITY

PART I.

1. [X] This communication is responsive to amendment filed on 11/7/94 & Supplemental amendment filed on 2/1/95.
2. [X] All the claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice Of Allowance And Issue Fee Due or other appropriate communication will be sent in due course.
3. [X] The allowed claims are 1-8.
4. [ ] The drawings filed on ______ are acceptable.
5. [ ] Acknowledgment is made of the claim for priority under 35 U.S.C. 119. The certified copy has [_] been received. [_] not been received. [_] been filed in parent application Serial No. ______, filed on ______.
6. [ ] Note the attached Examiner's Amendment.
7. [X] Note the attached Examiner Interview Summary Record, PTOL-413.
8. [ ] Note the attached Examiner's Statement of Reasons for Allowance.
9. [ ] Note the attached NOTICE OF REFERENCES CITED, PTO-892.
10. [ ] Note the attached INFORMATION DISCLOSURE CITATION, PTO-1449.

PART II.

A SHORTENED STATUTORY PERIOD FOR RESPONSE to comply with the requirements noted below is set to EXPIRE THREE MONTHS FROM THE "DATE MAILED" indicated on this form. Failure to timely comply will result in the ABANDONMENT of this application. Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

1. [ ] Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL APPLICATION, PTO-152, which discloses that the oath or declaration is deficient. A SUBSTITUTE OATH OR DECLARATION IS REQUIRED.
2. [X] APPLICANT MUST MAKE THE DRAWING CHANGES INDICATED BELOW IN THE MANNER SET FORTH ON THE REVERSE SIDE OF THIS PAPER.
   a. [X] Drawing informalities are indicated on the NOTICE RE PATENT DRAWINGS, PTO-948, attached hereto or to Paper No. 4. CORRECTION IS REQUIRED.
   b. [ ] The proposed drawing correction filed on ______ has been approved by the examiner. CORRECTION IS REQUIRED.
   c. [ ] Approved drawing corrections are described by the examiner in the attached EXAMINER'S AMENDMENT. CORRECTION IS REQUIRED.
   d. [X] Formal drawings are now REQUIRED.

Any response to this letter should include in the upper right hand corner, the following information from the NOTICE OF ALLOWANCE AND ISSUE FEE DUE: ISSUE BATCH NUMBER, DATE OF THE NOTICE OF ALLOWANCE, AND SERIAL NUMBER.

Attachments:

_ Examiner's Amendment
X Examiner Interview Summary Record, PTOL-413
_ Reasons for Allowance
_ Notice of References Cited, PTO-892
_ Information Disclosure Citation, PTO-1449
_ Notice of Informal Application, PTO-152
_ Notice re Patent Drawings, PTO-948
_ Listing of Bonded Draftsmen
_ Other

Young Tse
YOUNG TSE
PATENT EXAMINER
GROUP 2600

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EXHIBIT N

INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

V.90

(09/98)

SERIES V: DATA COMMUNICATION OVER THE TELEPHONE NETWORK

Simultaneous transmission of data and other signals

A digital modem and analogue modem pair for use on the Public Switched Telephone Network (PSTN) at data signalling rates of up to 56 000 bit/s downstream and up to 33 600 bit/s upstream

ITU-T Recommendation V.90

(Previously CCITT Recommendation)

ITU-T V-SERIES RECOMMENDATIONS

DATA COMMUNICATION OVER THE TELEPHONE NETWORK

General	V.1–V.9
Interfaces and voiceband modems	V.10–V.34
Wideband modems	V.35–V.39
Error control	V.40–V.49
Transmission quality and maintenance	V.50–V.59
Simultaneous transmission of data and other signals	**V.60–V.99**
Interworking with other networks	V.100–V.199
Interface layer specifications for data communication	V.200–V.249
Control procedures	V.250–V.299
Modems on digital circuits	V.300–V.399

For further details, please refer to ITU-T List of Recommendations.

ITU-T RECOMMENDATIONS SERIES

Series A	Organization of the work of the ITU-T
Series B	Means of expression: definitions, symbols, classification
Series C	General telecommunication statistics
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	Transmission systems and media, digital systems and networks
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	TMN and network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile and leased circuits
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	**Data communication over the telephone network**
Series X	Data networks and open system communications
Series Y	Global information infrastructure
Series Z	Programming languages

14610

Printed in Switzerland
Geneva, 1999

ITU-T RECOMMENDATION V.90

A DIGITAL MODEM AND ANALOGUE MODEM PAIR FOR USE ON THE PUBLIC SWITCHED TELEPHONE NETWORK (PSTN) AT DATA SIGNALLING RATES OF UP TO 56 000 bit/s DOWNSTREAM AND UP TO 33 600 bit/s UPSTREAM

Summary

This Recommendation specifies the operation of a digital modem and analogue modem pair for use on the Public Switched Telephone Network (PSTN) at data signalling rates of up to 56 000 bit/s in the downstream direction and up to 33 600 bit/s in the upstream direction. The two modems are specified herein in terms of coding, start-up signals and sequences, operating procedures and DTE-DCE interface functionalities. The network interface of the digital modem and the signalling rate that is used to connect the digital modem locally to a digital switched network are considered to be national matters and are hence not specified herein.

Source

ITU-T Recommendation V.90 was prepared by ITU-T Study Group 16 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 25th of September 1998.

FOREWORD

ITU (International Telecommunication Union) is the United Nations Specialized Agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the ITU. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation the term *recognized operating agency (ROA)* includes any individual, company, corporation or governmental organization that operates a public correspondence service. The terms *Administration, ROA* and *public correspondence* are defined in the *Constitution of the ITU (Geneva, 1992)*.

INTELLECTUAL PROPERTY RIGHTS

The ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. The ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, the ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

CONTENTS

Recommendation V.90

A DIGITAL MODEM AND ANALOGUE MODEM PAIR FOR USE ON THE PUBLIC SWITCHED TELEPHONE NETWORK (PSTN) AT DATA SIGNALLING RATES OF UP TO 56 000 bit/s DOWNSTREAM AND UP TO 33 600 bit/s UPSTREAM

(Geneva, 1998)

1 Scope

This Recommendation specifies the operation between two different modems, one a digital modem and the other an analogue modem, both as defined in clause 3. The two modems are specified herein in terms of coding, start-up signals and sequences, operating procedures and DTE-DCE interface functionalities. The network interface of the digital modem and the signalling rate that is used to connect the digital modem locally to a digital switched network are considered to be national matters and are hence not specified herein. The principal characteristics of these modems are as follows:

a) duplex mode of operation on the PSTN;

b) channel separation by echo cancellation techniques;

c) PCM modulation in the downstream direction at a symbol rate of 8000;

d) synchronous channel data signalling rates in the downstream direction from 28 000 bit/s to 56 000 bit/s in increments of 8000/6 bit/s;

e) V.34 modulation in the upstream direction;

f) synchronous channel data signalling rates in the upstream direction from 4800 bit/s to 28 800 bit/s in increments of 2400 bit/s, with optional support for 31 200 bit/s and 33 600 bit/s;

g) adaptive techniques that enable the modems to achieve close to the maximum data signalling rates the channel can support on each connection;

h) negotiate full duplex V.34 operation if a connection will not support V.90 operation;

i) exchange of rate sequences during start-up to establish the data signalling rate;

j) automoding to V-series modems supported by V.32 *bis* automode procedures and group 3 facsimile machines;

k) use of V.8, and optionally V.8 *bis*, procedures during modem start-up or selection.

2 References

The following Recommendations contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent editions of the Recommendations listed below. A list of currently valid ITU-T Recommendations is regularly published.

– CCITT Recommendation G.711 (1988), *Pulse Code Modulation (PCM) of voice frequencies*.

– ITU-T Recommendation T.30 (1996), *Procedures for document facsimile transmission in the general switched telephone network*.

– ITU-T Recommendation V.8 (1998), *Procedures for starting sessions of data transmission over the public switched telephone network*.

– ITU-T Recommendation V.8 *bis* (1996), *Procedures for the identification and selection of common modes of operation between Data Circuit-terminating Equipments (DCEs) and between Data Terminal Equipments (DTEs) over the public switched telephone network and on leased point-to-point telephone-type circuits*.

– ITU-T Recommendation V.14 (1993), *Transmission of start-stop characters over synchronous bearer channels*.

– ITU-T Recommendation V.24 (1998), *List of definitions for interchange circuits between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE)*.

– ITU-T Recommendation V.25 (1996), *Automatic answering equipment and general procedures for automatic calling equipment on the general switched telephone network including procedures for disabling of echo control devices for both manually and automatically established calls*.

– CCITT Recommendation V.32 *bis* (1991), *A duplex modem operating at data signalling rates of up to 14 400 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits*.

– ITU-T Recommendation V.34 (1998), *A modem operating at data signalling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits*.

– ITU-T Recommendation V.42 (1996), *Error-correcting procedures for DCEs using asynchronous-to-synchronous conversion*.

– ITU-T Recommendation V.43 (1998), *Data flow control*.

– ITU-T Recommendation V.80 (1996), *In-band DCE control and synchronous data modes for asynchronous DTE*.

3 Definitions

This Recommendation defines the following terms:

3.1 analogue modem: The analogue modem is the modem of the pair that, when in data mode, generates V.34 signals and receives G.711 signals that have been passed through a G.711 decoder. The modem is typically connected to a PSTN.

3.2 digital modem: The digital modem is the modem of the pair that, when in data mode, generates G.711 signals and receives V.34 signals that have been passed through a G.711 encoder. The modem is connected to a digital switched network through a digital interface, e.g. a Basic Rate Interface (BRI) or a Primary Rate Interface (PRI).

3.3 downstream: Transmission in the direction from the digital modem towards the analogue modem.

3.4 nominal transmit power: Reference transmit power that is configured by the user.

3.5 Uchord: Ucodes are grouped into eight Uchords. Uchord_1 contains Ucodes 0 to 15; Uchord_2 contains Ucodes 16 to 31; …; and Uchord_8 contains Ucodes 112 to 127.

3.6 Ucode: The universal code used to describe both a μ-law and an A-law PCM codeword. All universal codes are given in decimal notation in Table 1. The μ-law and A-law codewords are the octets to be passed to the digital interface by the digital modem and are given in hexadecimal notation. All modifications defined in Recommendation G.711 have already been made. The MSB in the μ-law PCM and A-law PCM columns in Table 1 corresponds to the polarity bit of the G.711 character signals. A linear representation of each PCM codeword is also given.

3.7 upstream: Transmission in the direction from the analogue modem towards the digital modem.

Table 1/V.90 – The universal set of PCM codewords

Ucode	µ-law PCM	µ-law linear	A-law PCM	A-law linear	Ucode	µ-law PCM	µ-law linear	A-law PCM	A-law linear
0	FF	0	D5	8	64	BF	1980	95	2112
1	FE	8	D4	24	65	BE	2108	94	2240
2	FD	16	D7	40	66	BD	2236	97	2368
3	FC	24	D6	56	67	BC	2364	96	2496
4	FB	32	D1	72	68	BB	2492	91	2624
5	FA	40	D0	88	69	BA	2620	90	2752
6	F9	48	D3	104	70	B9	2748	93	2880
7	F8	56	D2	120	71	B8	2876	92	3008
8	F7	64	DD	136	72	B7	3004	9D	3136
9	F6	72	DC	152	73	B6	3132	9C	3264
10	F5	80	DF	168	74	B5	3260	9F	3392
11	F4	88	DE	184	75	B4	3388	9E	3520
12	F3	96	D9	200	76	B3	3516	99	3648
13	F2	104	D8	216	77	B2	3644	98	3776
14	F1	112	DB	232	78	B1	3772	9B	3904
15	F0	120	DA	248	79	B0	3900	9A	4032
16	EF	132	C5	264	80	AF	4092	85	4224
17	EE	148	C4	280	81	AE	4348	84	4480
18	ED	164	C7	296	82	AD	4604	87	4736
19	EC	180	C6	312	83	AC	4860	86	4992
20	EB	196	C1	328	84	AB	5116	81	5248
21	EA	212	C0	344	85	AA	5372	80	5504
22	E9	228	C3	360	86	A9	5628	83	5760
23	E8	244	C2	376	87	A8	5884	82	6016
24	E7	260	CD	392	88	A7	6140	8D	6272
25	E6	276	CC	408	89	A6	6396	8C	6528
26	E5	292	CF	424	90	A5	6652	8F	6784
27	E4	308	CE	440	91	A4	6908	8E	7040
28	E3	324	C9	456	92	A3	7164	89	7296
29	E2	340	C8	472	93	A2	7420	88	7552
30	E1	356	CB	488	94	A1	7676	8B	7808
31	E0	372	CA	504	95	A0	7932	8A	8064
32	DF	396	F5	528	96	9F	8316	B5	8448
33	DE	428	F4	560	97	9E	8828	B4	8960
34	DD	460	F7	592	98	9D	9340	B7	9472
35	DC	492	F6	624	99	9C	9852	B6	9984
36	DB	524	F1	656	100	9B	10364	B1	10496
37	DA	556	F0	688	101	9A	10876	B0	11008
38	D9	588	F3	720	102	99	11388	B3	11520
39	D8	620	F2	752	103	98	11900	B2	12032

Table 1/V.90 – The universal set of PCM codewords *(concluded)*

Ucode	μ-law PCM	μ-law linear	A-law PCM	A-law linear	Ucode	μ-law PCM	μ-law linear	A-law PCM	A-law linear
40	D7	652	FD	784	104	97	12412	BD	12544
41	D6	684	FC	816	105	96	12924	BC	13056
42	D5	716	FF	848	106	95	13436	BF	13568
43	D4	748	FE	880	107	94	13948	BE	14080
44	D3	780	F9	912	108	93	14460	B9	14592
45	D2	812	F8	944	109	92	14972	B8	15104
46	D1	844	FB	976	110	91	15484	BB	15616
47	D0	876	FA	1008	111	90	15996	BA	16128
48	CF	924	E5	1056	112	8F	16764	A5	16896
49	CE	988	E4	1120	113	8E	17788	A4	17920
50	CD	1052	E7	1184	114	8D	18812	A7	18944
51	CC	1116	E6	1248	115	8C	19836	A6	19968
52	CB	1180	E1	1312	116	8B	20860	A1	20992
53	CA	1244	E0	1376	117	8A	21884	A0	22016
54	C9	1308	E3	1440	118	89	22908	A3	23040
55	C8	1372	E2	1504	119	88	23932	A2	24064
56	C7	1436	ED	1568	120	87	24956	AD	25088
57	C6	1500	EC	1632	121	86	25980	AC	26112
58	C5	1564	EF	1696	122	85	27004	AF	27136
59	C4	1628	EE	1760	123	84	28028	AE	28160
60	C3	1692	E9	1824	124	83	29052	A9	29184
61	C2	1756	E8	1888	125	82	30076	A8	30208
62	C1	1820	EB	1952	126	81	31100	AB	31232
63	C0	1884	EA	2016	127	80	32124	AA	32256

4 Abbreviations

This Recommendation uses the following abbreviations:

BRI Basic Rate Interface

DCE Data Circuit-terminating Equipment

DIL Digital Impairment Learning sequence

DTE Data Terminal Equipment

PRI Primary Rate Interface

PSTN Public Switched Telephone Network

RMS Root Mean Square

RTDEa Round-Trip Delay Estimate – Analogue modem

RTDEd Round-Trip Delay Estimate – Digital modem

U_{INFO} The Ucode given by bits 25:31 of $INFO_{1a}$

5 Digital modem

5.1 Data signalling rates

Synchronous channel data signalling rates from 28 000 bit/s to 56 000 bit/s in increments of 8000/6 bit/s shall be supported. The data signalling rate shall be determined during Phase 4 of modem start-up according to the procedures described in 9.4.

5.2 Symbol rate

The downstream symbol rate shall be 8000 established by timing from the digital network interface. The digital modem shall support the upstream symbol rates 3000 and 3200. It may also support the optional upstream symbol rate 3429 as defined in Recommendation V.34.

5.3 Scrambler

The digital modem shall include a self-synchronizing scrambler as specified in clause 7/V.34, using the generating polynomial, GPC, in equation 7-1/V.34.

5.4 Encoder

The block diagram in Figure 1 is an overview of the encoder and represents one data frame. Data frames in the digital modem have a six-symbol structure. Each symbol position within the data frame is called a data frame interval and is indicated by a time index, i = 0, …, 5, where i = 0 is the first in time. Frame synchronization between the digital modem transmitter and analogue modem receiver is established during training procedures.

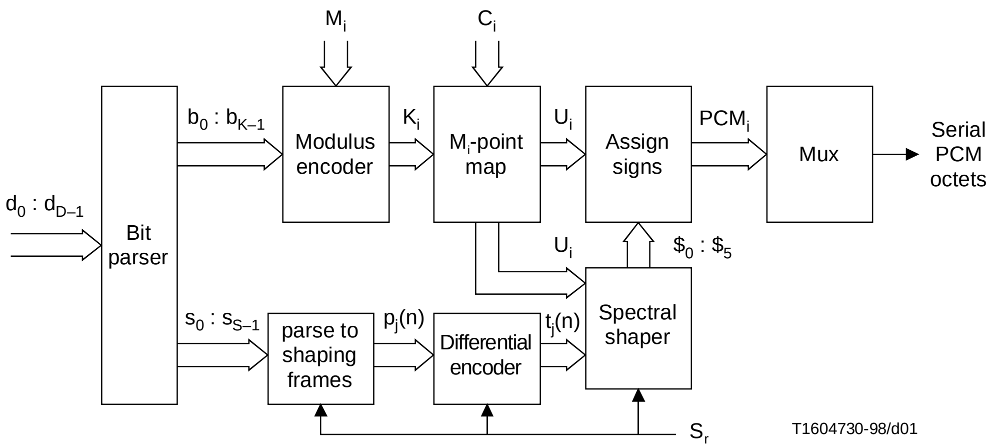

Figure 1/V.90 – Digital modem encoder block diagram

5.4.1 Mapping parameters

Mapping parameters, established during training or rate renegotiation procedures, are:

– six PCM code sets, one for each data frame interval 0 to 5, where data frame interval i has M_i members;

– K, the number of modulus encoder input data bits per data frame;

– S_r, the number of PCM code sign bits per data frame used as redundancy for spectral shaping; and

– S, the number of spectral shaper input data bits per data frame, where $S + S_r = 6$.

Table 2 shows the data signalling rates achieved by the valid combinations of K and S during data mode. Table 17 shows the valid combinations of K and S used during Phase 4 and rate renegotiation procedures.

Table 2/V.90 – Data signalling rates for different K and S

K, bits entering modulus encoder	S, sign bits used for user data		Data Signalling Rate, kbit/s	
	From	To	From	To
15	6	6	28	28
16	5	6	28	29 1/3
17	4	6	28	30 2/3
18	3	6	28	32
19	3	6	29 1/3	33 1/3
20	3	6	30 2/3	34 2/3
21	3	6	32	36
22	3	6	33 1/3	37 1/3
23	3	6	34 2/3	38 2/3
24	3	6	36	40
25	3	6	37 1/3	41 1/3
26	3	6	38 2/3	42 2/3
27	3	6	40	44
28	3	6	41 1/3	45 1/3
29	3	6	42 2/3	46 2/3
30	3	6	44	48
31	3	6	45 1/3	49 1/3
32	3	6	46 2/3	50 2/3
33	3	6	48	52
34	3	6	49 1/3	53 1/3
35	3	6	50 2/3	54 2/3
36	3	6	52	56
37	3	5	53 1/3	56
38	3	4	54 2/3	56
39	3	3	56	56

5.4.2 Input bit parsing

D (equal to S + K) serial input data bits, d_0 to d_{D-1} where d_0 is first in time, are parsed into S sign input bits and K modulus encoder bits. d_0 to d_{S-1} form s_0 to s_{S-1} and d_S to d_{D-1} form b_0 to b_{K-1}.

The K modulus encoder bits and the S sign bits are used as specified in 5.4.3 and 5.4.5 respectively.

5.4.3 Modulus encoder

K bits enter the modulus encoder. The data signalling rates associated with each value of K are tabulated in Table 2. There are six independent mapping moduli, M_0 to M_5, which are the number of members in the PCM code sets defined for data frame interval 0 to data frame interval 5, respectively. M_i is equal to the number of positive levels in the constellation to be used in data frame interval i as signalled by the analogue modem using the CP sequences defined in 8.5.2.

The values of M_i and K shall satisfy the inequality $2^K \leq \prod_{i=0}^{5} M_i$

The modulus encoder converts K bits into six numbers, K_0 to K_5, using the following algorithm.

NOTE – Other implementations are possible but the mapping function must be identical to that given in the algorithm described below.

1) Represent the incoming K bits as an integer, R_0:

$$R_0 = b_0 + b_1*2^1 + b_2*2^2 + ... + b_{K-1}*2^{K-1}$$

2) Divide R_0 by M_0. The remainder of this division gives K_0, the quotient becomes R_1 for use in the calculation for the next data frame interval. Continue for the remaining five data frame intervals. This gives K_0 to K_5 as:

$$K_i = R_i \text{ modulo } M_i, \text{ where } 0 \leq K_i < M_i; R_{i+1} = (R_i - K_i) / M_i$$

3) The numbers K_0, …, K_5 are the output of the modulus encoder, where K_0 corresponds to data frame interval 0 and K_5 corresponds to data frame interval 5.

5.4.4 Mapper

There are six independent mappers associated with the six data frame intervals. Each mapper uses a tabulation of M_i PCM codes that make up the positive constellation points of data frame interval i denoted C_i. The PCM codes to be used in each data frame interval are specified by the analogue modem during training procedures. The PCM code that is denoted by the largest (smallest) Ucode is herein called the largest (smallest) PCM code. The members of C_i shall be labelled in descending order so that label 0 corresponds to the largest PCM code in C_i, label $M_i - 1$ corresponds to the smallest PCM code in C_i. Each mapper takes K_i and forms U_i by choosing the constellation point in C_i labelled by K_i.

5.4.5 Spectral shaping

The digital modem output line signal spectrum shall be shaped, if spectral shaping is enabled. Spectral shaping only affects the sign bits of transmitted PCM symbols. In every data frame of 6 symbol intervals, S_r sign bits are used as redundancy for spectral shaping while the remaining S sign bits carry user information. The redundancy, S_r, is specified by the analogue modem during training procedures and can be 0, 1, 2 or 3. When $S_r = 0$, spectral shaping is disabled.

NOTE – The initial state of the spectral shaper does not affect the performance of the analogue modem and is therefore left to the implementor.

5.4.5.1 $S_r = 0, S = 6$

The PCM code sign bits, $\$_0$ to $\$_5$ shall be assigned using input sign bits s_0 to s_5 and a differential coding rule:

$$\$_0 = s_0 \oplus (\$_5 \text{ of the previous data frame}); \text{ and}$$

$$\$_i = s_i \oplus \$_{i-1} \text{ for } i = 1, ..., 5$$

where "⊕" stands for modulus-2 addition.

5.4.5.2 $S_r = 1, S = 5$

Sign bits s_0 to s_4 shall be parsed to one six-bit shaping frame per data frame according to Table 3.

The odd bits shall be differentially encoded to produce the output p'_j according to Table 4.

Table 3/V.90 – Parsing input sign bits to shaping frames

Data frame interval	$S_r = 1, S = 5$	$S_r = 2, S = 4$	$S_r = 3, S = 3$
0	$p_j(0) = 0$	$p_j(0) = 0$	$p_j(0) = 0$
1	$p_j(1) = s_0$	$p_j(1) = s_0$	$p_j(1) = s_0$
2	$p_j(2) = s_1$	$p_j(2) = s_1$	$p_{j+1}(0) = 0$
3	$p_j(3) = s_2$	$p_{j+1}(0) = 0$	$p_{j+1}(1) = s_1$
4	$p_j(4) = s_3$	$p_{j+1}(1) = s_2$	$p_{j+2}(0) = 0$
5	$p_j(5) = s_4$	$p_{j+1}(2) = s_3$	$p_{j+2}(1) = s_2$

Table 4/V.90 – Odd bit differential coding

Data frame interval	$S_r = 1, S = 5$	$S_r = 2, S = 4$	$S_r = 3, S = 3$
0	$p'_j(0) = 0$	$p'_j(0) = 0$	$p'_j(0) = 0$
1	$p'_j(1) = p_j(1) \oplus p'_{j-1}(5)$	$p'_j(1) = p_j(1) \oplus p'_{j-1}(1)$	$p'_j(1) = p_j(1) \oplus p'_{j-1}(1)$
2	$p'_j(2) = p_j(2)$	$p'_j(2) = p_j(2)$	$p'_{j+1}(0) = 0$
3	$p'_j(3) = p_j(3) \oplus p'_j(1)$	$p'_{j+1}(0) = 0$	$p'_{j+1}(1) = p_{j+1}(1) \oplus p'_j(1)$
4	$p'_j(4) = p_j(4)$	$p'_{j+1}(1) = p_{j+1}(1) \oplus p'_j(1)$	$p'_{j+2}(0) = 0$
5	$p'_j(5) = p_j(5) \oplus p'_j(3)$	$p'_{j+1}(2) = p_{j+1}(2)$	$p'_{j+2}(1) = p_{j+2}(1) \oplus p'_{j+1}(1)$

Finally, a second differential encoding shall be performed to produce the initial shaping sign bit assignment, $t_j(0)$ to $t_j(5)$ using the rule:

$$t_j(k) = p'_j(k) \oplus t_{j-1}(k)$$

The spectral shaper converts each bit $t_j(k)$, to a PCM code sign bit $\$_k$ as described in 5.4.5.5.

5.4.5.3 $S_r = 2, S = 4$

Sign bits s_0 to s_3 shall be parsed to two three-bit shaping frames per data frame as shown in Table 3.

The odd bit in each shaping frame shall be differentially encoded to produce differentially encoded outputs p'_j and p'_{j+1} according to Table 4.

Finally, a second differential encoding shall be performed on each shaping frame to produce the initial shaping sign bit assignments $t_j(0)$ to $t_j(2)$ and $t_{j+1}(0)$ to $t_{j+1}(2)$ using the differential encoding rule:

$$t_j(k) = p'_j(k) \oplus t_{j-1}(k)$$

$$t_{j+1}(k) = p'_{j+1}(k) \oplus t_j(k)$$

The spectral shaper converts each bit $t_j(k)$, to PCM code sign bit $\$_k$ and each bit $t_{j+1}(k)$, to PCM code sign bit $\$_{k+3}$ as described in 5.4.5.5.

5.4.5.4 $S_r = 3, S = 3$

Sign bits s_0 to s_2 shall be parsed to three two-bit shaping frames per data frame as shown in Table 3.

The odd bit in each shaping frame shall be differentially encoded to produce differentially encoded outputs p'_j, p'_{j+1}, and p'_{j+2} as shown in Table 4.

Finally, a second differential encoding shall be performed on each shaping frame to produce the initial shaping sign bit assignments $t_j(0)$ to $t_j(1)$, $t_{j+1}(0)$ to $t_{j+1}(1)$, and $t_{j+2}(0)$ to $t_{j+2}(1)$ using the differential encoding rule:

$$t_j(k) = p'_j(k) \oplus t_{j-1}(k)$$

$$t_{j+1}(k) = p'_{j+1}(k) \oplus t_j(k)$$

$$t_{j+2}(k) = p'_{j+2}(k) \oplus t_{j+1}(k)$$

The spectral shaper converts each bit $t_j(k)$, to PCM code sign bit $\$_k$, each bit $t_{j+1}(k)$, to PCM code sign bit $\$_{k+2}$, and each bit $t_{j+2}(k)$, to PCM code sign bit $\$_{k+4}$ as described in 5.4.5.5.

5.4.5.5 Spectral shaper

The spectral shaper operates on a spectral shaper frame basis. For the cases $S_r = 2$ and $S_r = 3$, there are multiple shaper frames per six-symbol data frame. Spectral shaper operation for each shaper frame within a data frame (called shaping frame j in this subclause) is identical except that they affect different data frame PCM sign bits as shown in Table 5.

Table 5/V.90 – Shaping frame to data frame sign relationship

Data frame interval	$S_r = 1, S = 5$	$S_r = 2, S = 4$	$S_r = 3, S = 3$	Data frame PCM sign bit
0	$t_j(0)$	$t_j(0)$	$t_j(0)$	$\$_0$
1	$t_j(1)$	$t_j(1)$	$t_j(1)$	$\$_1$
2	$t_j(2)$	$t_j(2)$	$t_{j+1}(0)$	$\$_2$
3	$t_j(3)$	$t_{j+1}(0)$	$t_{j+1}(1)$	$\$_3$
4	$t_j(4)$	$t_{j+1}(1)$	$t_{j+2}(0)$	$\$_4$
5	$t_j(5)$	$t_{j+1}(2)$	$t_{j+2}(1)$	$\$_5$

The spectral shaper shall modify the initial sign bits [$t_j(0)$, $t_j(1)$, …] to corresponding PCM code sign bits ($\$_0$, $\$_1$ …) without violating the constraint described below, so as to optimize a spectral metric.

The constraint of the spectral shaper is described using the 2-state trellis diagram shown in Figure 2.

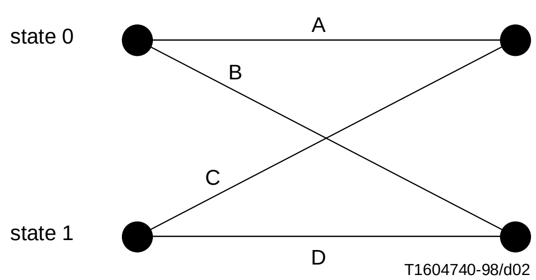

Figure 2/V.90 – Trellis diagram used to constrain the spectral shaper

In a given spectral shaping frame j, the spectral shaper shall modify the initial sign sequence, $t_j(k)$, according to one of the following four sign inversion rules:

– Rule A: Do nothing;

– Rule B: Invert all sign bits in spectral shaping frame j;

– Rule C: Invert even-numbered [$t_j(0)$, $t_j(2)$, etc.] sign bits in spectral shaping frame j;

– Rule D: Invert odd-numbered [$t_j(1)$, $t_j(3)$, etc.] sign bits in spectral shaping frame j.

The trellis diagram describes the sequence of sign inversion rules that are allowable. For example, when the spectral shaper is in state $Q_j = 0$ at the beginning of frame j, only rules A and B are allowable in frame j. The current state Q_j together with the sign inversion rule selected for frame j determine the next state Q_{j+1} according to the trellis diagram.

The look-ahead depth parameter, ld, is an integer between 0 and 3 selected by the analogue modem during training procedures. Id of 0 and 1 are mandatory in the digital modem. Id of 2 and 3 are optional.

To select the sign inversion rule for the j^{th} spectral shaping frame, the spectral shaper shall use the PCM symbol magnitudes produced by the mapper for spectral shaping frames j, j+1, ..., j+ld. It shall compute the spectral metric that would result if each of the allowable sequences of sign inversion rules for frames j through j+ld, starting from the current state Q_j in frame j, were to be used. The shaper shall select the sign inversion rule for frame j that minimizes the spectral metric, w[n], defined in 5.4.5.6 up to and including the final symbol of spectral shaping frame j+ld. The selection determines the next state Q_{j+1}.

The shaper shall then set PCM code signs $\$_i$ for shaping frame j according to the selected sign inversion rule for shaper frame j.

5.4.5.6 Spectral shape filter

The analogue modem determines the spectral shape filter function used in the digital modem by selecting parameters of the following transfer function:

$$T(z) = \frac{(1-a_1z^{-1})(1-a_2z^{-1})}{(1-b_1z^{-1})(1-b_2z^{-1})}$$

where a_1, a_2, b_1 and b_2 are parameters having absolute values less than or equal to 1. The parameters, a_1, a_2, b_1 and b_2, are specified by the analogue modem during training procedures and are represented in the 8-bit two's-complement format with 6 bits after the binary point. The digital modem shall perform the spectral shaping according to the spectral shaping metric, w[n], characterised by the filter:

$$F(z) = \frac{1}{T(z)} = \frac{(1-b_1z^{-1})(1-b_2z^{-1})}{(1-a_1z^{-1})(1-a_2z^{-1})}$$

The filter input, x[n], shall be a signed signal proportional to the linear value corresponding to PCM codes being transmitted. The relationship between PCM codes and corresponding linear values is given in Table 1. w[n] shall be computed as:

1) $y[n] = x[n] - b_1x[n-1] + a_1y[n-1]$

2) $v[n] = y[n] - b_2y[n-1] + a_2v[n-1]$

3) $w[n] = v^2[n] + w[n-1]$

5.4.6 Sign assignment

Six sign bits, generated by 5.4.5, are attached to the six unsigned mapper outputs $U_0 - U_5$ to complete the mapping of the data frame intervals. A sign bit of 0 means the transmitted PCM codeword will represent a negative voltage and a sign bit of 1 means it will represent a positive voltage.

5.4.7 Mux

The signed PCM codewords, PCM_i, are transmitted from the digital modem sequentially with PCM_0 being first in time.

6 Analogue modem

The characteristics of the analogue modem described herein apply when in V.90 mode. After fallback to V.34 mode, the analogue modem shall have characteristics as defined in Recommendation V.34.

6.1 Data signalling rates

The modem shall support synchronous data signalling rates of 4800 bit/s to 28 800 bit/s in increments of 2400 bit/s, with optional support for 31 200 bit/s and 33 600 bit/s. The 200 bit/s V.34 auxiliary channel is not supported. The data signalling rate shall be determined during Phase 4 of modem start-up according to the procedures described in 9.4.

6.2 Symbol rates

The analogue modem shall support the symbol rate 3200. It may also support 3000 and the optional symbol rate 3429 as defined in Recommendation V.34. The other V.34 symbol rates, 2400, 2743 and 2800, shall not be supported. The symbol rate shall be selected by the analogue modem during Phase 2 of modem start-up according to the procedures described in 9.2.

6.3 Carrier frequencies

The analogue modem shall support the carrier frequencies specified in 5.3/V.34 for the appropriate symbol rate. The carrier frequency shall be determined during Phase 2 of modem start-up according to the procedures specified in 9.2.

6.4 Pre-emphasis

The analogue modem shall support the pre-emphasis filter characteristics specified in 5.4/V.34. The filter selection shall be provided by the digital modem during Phase 2 of modem start-up according to the procedures specified in 9.2.

6.5 Scrambler

The analogue modem shall include a self-synchronizing scrambler as specified in clause 7/V.34, using the generating polynomial, GPA, in equation 7-2/V.34.

6.6 Framing

The analogue modem shall use the framing method specified for the V.34 primary channel in clause 8/V.34.

6.7 Encoder

The analogue modem shall use the encoder specified for the V.34 primary channel in clause 9/V.34.

7 Interchange circuits

The requirements of this clause apply to both modems.

7.1 List of interchange circuits

References in this Recommendation to V.24 interchange circuit numbers are intended to refer to the functional equivalent of such circuits and are not intended to imply the physical implementation of such circuits. For example, references to circuit 103 should be understood to refer to the functional equivalent of circuit 103 (see Table 6).

7.2 Asynchronous character-mode interfacing

The modem may include an asynchronous-to-synchronous converter interfacing to the DTE in an asynchronous (or start-stop character) mode. The protocol for the conversion shall be in accordance with Recommendation(s) V.14, V.42 or V.80. Data compression may also be employed.

8 Start-up signals and sequences

All PCM codewords transferred in training sequences are described using the universal codes as specified in Table 1.

Table 6/V.90 – Interchange circuits

Interchange circuit		Notes
No.	**Description**	
102	Signal ground or common return	
103	Transmitted data	
104	Received data	
105	Request to send	
106	Ready for sending	
107	Data set ready	
108/1 or	Connect data set to line	
108/2	Data terminal ready	
109	Data channel received line signal detector	1
125	Calling indicator	
133	Ready for receiving	2

NOTE 1 – Thresholds and response times are not applicable because a line signal detector cannot be expected to distinguish received signals from talker echoes.

NOTE 2 – Operation of circuit 133 shall be in accordance with 4.2.1.1/V.43.

8.1 Phase 1

Recommendation V.8, and optionally Recommendation V.8 *bis*, is used in Phase 1. All signals in 9.1 are defined in either Recommendation V.25 or Recommendation V.8 and shall be transmitted at the nominal transmit power level.

8.2 Phase 2

During Phase 2, all signals except L1 shall be transmitted at the nominal transmit power level. If a recovery mechanism returns the modem to Phase 2 from a later phase, the transmit level shall revert to the nominal transmit power from the previously negotiated transmit power level.

8.2.1 A

As defined in 10.1.2.1/V.34.

8.2.2 B

As defined in 10.1.2.2/V.34.

8.2.3 INFO sequences

INFO sequences are used to exchange modem capabilities, results of line probing, and data mode modulation parameters.

8.2.3.1 Modulation

All INFO sequences are transmitted using binary DPSK modulation at 600 bit/s ± 0.01%. The transmit point is rotated 180 degrees from the previous point if the transmit bit is a 1, and the transmit point is rotated 0 degrees from the previous point if the transmit bit is a 0. Each INFO sequence is preceded by a point at an arbitrary carrier phase. When multiple INFO sequences are transmitted as a group, only the first sequence is preceded by a point at an arbitrary carrier phase.

INFO sequences are transmitted by the analogue modem with a carrier frequency of 2400 Hz ± 0.01%, at 1 dB below the nominal transmit power, plus an 1800 Hz ± 0.01% guard tone 7 dB below the nominal transmit power. INFO sequences are transmitted by the digital modem with a carrier frequency of 1200 Hz ± 0.01% at the nominal transmit power.

The transmitted line signal shall have a magnitude spectrum within the limits shown in Figure 13/V.34.

NOTE – It is highly desirable to design linear phase transmitter channel separation and shaping filters since there are no provisions for adaptive equaliser training.

8.2.3.2 INFO information bits

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 7 defines the bits in the $INFO_{0d}$ sequence. Bit 0 is transmitted first in time.

Table 7/V.90 – Definition of bits in $INFO_{0d}$

$INFO_{0d}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12	Set to 1 indicates symbol rate 2743 is supported in V.34 mode
13	Set to 1 indicates symbol rate 2800 is supported in V.34 mode
14	Set to 1 indicates symbol rate 3429 is supported in V.34 mode
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting in V.34 mode
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions in V.34 mode. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps
24	Set to 1 in an $INFO_{0d}$ sequence transmitted from a CME modem
25	Set to 1 indicates the ability to support up to 1664 point signal constellations
26:27	Reserved for the ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
28	Set to 1 to acknowledge correct reception of an $INFO_{0a}$ frame during error recovery
29:32	Digital modem nominal transmit power for Phase 2. This is represented in –1 dBm0 steps where 0 represents –6 dBm0 and 15 represents –21 dBm0
33:37	Maximum digital modem transmit power. This is represented in –0.5 dBm0 steps where 0 represents –0.5 dBm0 and 31 represents –16 dBm0
38	Set to 1 indicates the digital modem's power shall be measured at the output of the codec. Otherwise the digital modem's power shall be measured at its terminals
39	PCM coding in use by digital modem: 0 = µ-law, 1 = A-law
40	Set to 1 indicates ability to operate V.90 with an upstream symbol rate of 3429
41	Reserved for the ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
42:57	CRC
58:61	Fill bits: 1111

NOTE 1 – Bits 12, 13, 14 and 40 are used to indicate the modem's capabilities and/or configuration. The values of bits 15 to 20 depend upon regulatory requirements and apply only to the modem's transmitter.

NOTE 2 – Bit 24 may be used in conjunction with the PSTN access category octet defined in Recommendation V.8 to determine the optimum parameters for the signal convertors and error-control functions in the analogue and digital modem and any intervening CME.

Table 8 defines the bits in the $INFO_{0a}$ sequence. Bit 0 is transmitted first in time.

Table 8/V.90 – Definition of bits in $INFO_{0a}$

$INFO_{0a}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12	Set to 1 indicates symbol rate 2743 is supported in V.34 mode
13	Set to 1 indicates symbol rate 2800 is supported in V.34 mode
14	Set to 1 indicates symbol rate 3429 is supported in V.34 mode
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions in V.34 mode. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps
24	Set to 1 in an $INFO_{0a}$ sequence transmitted from a CME modem
25	Set to 1 indicates the ability to support up to 1664 point signal constellations
26:27	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
28	Set to 1 to acknowledge correct reception of an $INFO_{0d}$ frame during error recovery
29:44	CRC
45:48	Fill bits: 1111

NOTE 1 – Bits 12 to 14 are used to indicate the modem's capabilities and/or configuration. The values of bits 15 to 20 depend upon regulatory requirements and apply only to the modem's transmitter.

NOTE 2 – Bit 24 may be used in conjunction with the PSTN access category octet defined in Recommendation V.8 to determine the optimum parameters for the signal convertors and error-control functions in the analogue and digital modem and any intervening CME.

Table 9 defines the bits in the $INFO_{1d}$ sequence. The bit definitions are identical to those of $INFO_{1c}$ in Recommendation V.34 and are given here for convenience. Bit 0 is transmitted first in time.

Table 9/V.90 – Definition of bits in $INFO_{1d}$

$INFO_{1d}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:14	Minimum power reduction to be implemented by the analogue modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if $INFO_{0a}$ indicated that the analogue modem transmitter cannot reduce its power
15:17	Additional power reduction, below that indicated by bits 12:14, which can be tolerated by the digital modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if $INFO_{0a}$ indicated that the analogue modem transmitter cannot reduce its power
18:24	Length of MD to be transmitted by the digital modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the analogue modem to the digital modem for a symbol rate of 2400
26:29	Pre-emphasis filter to be used in transmitting from the analogue modem to the digital modem for a symbol rate of 2400. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3/V.34 and 4/V.34)
30:33	Projected maximum data rate for a symbol rate of 2400. These bits form an integer between 0 and 14 which gives the projected data rate as a multiple of 2400 bits/s. A 0 indicates the symbol rate cannot be used
34:42	Probing results pertaining to a final symbol rate selection of 2743 symbols per second. The coding of these 9 bits is identical to that for bits 25-33
43:51	Probing results pertaining to a final symbol rate selection of 2800 symbols per second. The coding of these 9 bits is identical to that for bits 25-33
52:60	Probing results pertaining to a final symbol rate selection of 3000 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in $INFO_{0a}$
61:69	Probing results pertaining to a final symbol rate selection of 3200 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in $INFO_{0a}$
70:78	Probing results pertaining to a final symbol rate selection of 3429 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in $INFO_{0a}$
79:88	Frequency offset of the probing tones as measured by the digital modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 88 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to –512 indicating that this field is to be ignored
89:104	CRC
105:108	Fill bits: 1111
NOTE 1 – Projected maximum data rates greater than 12 in bits 30:33 shall only be indicated when the analogue modem supports up to 1664 point signal constellations. NOTE 2 – The analogue modem may be able to achieve a higher downstream data signalling rate in V.90 mode if the digital modem indicates that the analogue modem may transmit at a lower power in bits 15:17.	

Table 10 defines the bits in the $INFO_{1a}$ sequence that an analogue modem uses to request Phase 3 of this Recommendation. Bits 37:39 represent the integer 6, indicating that V.90 operation is desired. Bit 0 is transmitted first in time.

Table 10/V.90 – Definition of bits in $INFO_{1a}$ when V.90 is selected

$INFO_{1a}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:17	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
18:24	Length of MD to be transmitted by the analogue modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments
25:31	U_{INFO}: Ucode of the PCM codeword to be used by the digital modem for the 2 point train. The power of this point shall not exceed the maximum digital modem transmit power. U_{INFO} shall be greater than 66
32:33	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
34:36	Symbol rate to be used in transmitting from the analogue modem to the digital modem. An integer between 3 and 5 gives the symbol rate, where 3 represents 3000 and 5 represents 3429. The symbol rate selected shall be consistent with information in $INFO_{1d}$. The carrier frequency and pre-emphasis filter to be used are those already indicated for this symbol rate in $INFO_{1d}$
37:39	Symbol rate of 8000 to be used by the digital modem: The integer 6
40:49	Frequency offset of the probing tones as measured by the analogue modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 9 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to –512 indicating that this field is to be ignored
50:65	CRC
66:69	Fill bits: 1111

Table 11 defines the bits in the $INFO_{1a}$ sequence that an analogue modem uses to request Phase 3 of Recommendation V.34. The bit definitions are identical to those of $INFO_{1a}$ in Recommendation V.34 and are given here for convenience. Bits 37:39 represent an integer between 0 and 5, indicating that V.34 operation is desired. Bit 0 is transmitted first in time.

8.2.3.3 INFOMARKS

$INFOMARKS_d$ is created by the digital modem applying binary ones to the DPSK modulator described in 8.2.3.1.

$INFOMARKS_a$ is created by the analogue modem applying binary ones to the DPSK modulator described in 8.2.3.1.

8.2.4 Line probing signals

As defined in 10.1.2.4/V.34.

8.3 Phase 3 signals for the analogue modem

The analogue modem shall use the polynomial, GPA, in equation 7-2/V.34 when generating signals J_a, TRN and SCR.

Table 11/V.90 – Definition of bits in $INFO_{1a}$ when V.34 is selected

$INFO_{1a}$ bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:14	Minimum power reduction to be implemented by the digital modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if $INFO_{0d}$ indicated that the digital modem transmitter cannot reduce its power
15:17	Additional power reduction, below that indicated by bits 12:14, which can be tolerated by the analogue modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if $INFO_{0d}$ indicated that the digital modem transmitter cannot reduce its power
18:24	Length of MD to be transmitted by the analogue modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the digital modem to the analogue modem. This shall be consistent with the capabilities of the digital modem indicated in $INFO_{0d}$
26:29	Pre-emphasis filter to be used in transmitting from the digital modem to the analogue modem. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3/V.34 and 4/V.34)
30:33	Projected maximum data rate for the selected symbol rate from the digital modem to the analogue modem. These bits form an integer between 0 and 14 which gives the projected data rate as a multiple of 2400 bits/s
34:36	Symbol rate to be used in transmitting from the analogue modem to the digital modem. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429. The symbol rate selected shall be consistent with information in $INFO_{1d}$ and consistent with the symbol rate asymmetry allowed as indicated in $INFO_{0a}$ and $INFO_{0d}$. The carrier frequency and pre-emphasis filter to be used are those already indicated for this symbol rate in $INFO_{1d}$
37:39	Symbol rate to be used in transmitting from the digital modem to the analogue modem. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429. The symbol rate selected shall be consistent with the capabilities indicated in $INFO_{0a}$ and consistent with the symbol rate asymmetry allowed as indicated in $INFO_{0a}$ and $INFO_{0d}$
40:49	Frequency offset of the probing tones as measured by the analogue modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 49 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to –512 indicating that this field is to be ignored
50:65	CRC
66:69	Fill bits: 1111
NOTE – Projected maximum data rates greater than 12 in bits 30:33 shall only be indicated when the digital modem supports up to 1664 point signal constellations.	

8.3.1 J_a

Sequence J_a consists of repetitions of the DIL descriptor detailed below. The modulation used for transmitting J_a is as defined in 10.1.3.3/V.34. Transmission of sequence J_a may be terminated without completing the final DIL descriptor.

The DIL descriptor tells the digital modem what parameters to use when transmitting DIL. The bit fields in the DIL descriptor are given in Table 12. Definitions and interpretation of the parameters are given in 8.4.1. Due to the variability in the length of the sequences SP and TP the bit numbers are given using $\alpha = \lceil (L_{SP})/16 \rceil * 17$ and $\beta = \alpha + \lceil (L_{TP})/16 \rceil * 17$, where $\lceil x \rceil$ is the smallest integer higher than or equal to x. When L_{SP} is not a multiple of 16, zeroes shall be used to pad SP to the next multiple of 16 bits so that the format of the J_a sequence is preserved. Similarly, when L_{TP} is not a multiple of 16, zeroes shall be used to pad TP to the next multiple of 16 bits. $L_{SP} - 1 = L_{TP} - 1 = 0$ when $N = 0$. The values for SP and TP have no significance when $N = 0$.

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 12/V.90 – Definition of bits in the DIL descriptor

LSB:MSB	Definition
0:16	Frame sync: 11111111111111111
17	Start bit: 0
18:25	N
26:33	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
34	Start bit: 0
35:41	$L_{SP} – 1$
42	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
43:49	$L_{TP} – 1$
50	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
51	Start bit: 0
52:67	SP
68	Start bit: 0
	Possible continuation of SP with a start bit (0) every 16 bits
51+α	Start bit: 0
52+α:67+α	TP
68+α	Start bit: 0
	Possible continuation of TP with a start bit (0) every 16 bits
51+β	Start bit: 0
52+β:58+β	H_1
59+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
60+β:66+β	H_2
67+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
68+β	Start bit: 0
69+β:75+β	H_3
76+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
77+β:83+β	H_4
84+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
85+β	Start bit: 0
86+β:92+β	H_5
93+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
94+β:100+β	H_6
101+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
102+β	Start bit: 0
103+β:109+β	H_7
110+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem

Table 12/V.90 – Definition of bits in the DIL descriptor *(concluded)*

LSB:MSB	Definition
111+β:117+β	H_8
118+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
119+β	Start bit: 0
120+β:126+β	REF_1
127+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
128+β:134+β	REF_2
135+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
136+β	Start bit: 0
137+β:143+β	REF_3
144+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
145+β:151+β	REF_4
152+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
153+β	Start bit: 0
154+β:160+β	REF_5
161+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
162+β:168+β	REF_6
169+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
170+β	Start bit: 0
171+β:177+β	REF_7
178+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
179+β:185+β	REF_8
186+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
187+β	Start bit: 0
188+β:194+β	The Ucode of the training symbol used for the 1st DIL segment
195+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
196+β:202+β	The Ucode of the training symbol used for the 2nd DIL segment
203+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
204+β	Start bit: 0
	Remaining Ucodes of training symbols with a start bit (0) every 16 bits and appropriate reserved bits including 9 reserved bits to fill the final 16 bits if N is odd
$187+\beta+\lceil N/2 \rceil*17$	Start bit: 0
$188+\beta+\lceil N/2 \rceil*17$: $203+\beta+\lceil N/2 \rceil*17$	CRC
$204+\beta+\lceil N/2 \rceil*17$	Fill bit: 0
$205+\beta+\lceil N/2 \rceil*17$	Fill bit: 0 may be necessary to ensure that the descriptor has an even number of bits.

NOTE – It is highly desirable that the analogue modem requests a DIL that does not allow echo control devices in the switched digital network to re-enable. The analogue modem may also continuously transmit SCR during the reception of DIL to maintain line energy.

8.3.2 MD

As defined in 10.1.3.5/V.34.

8.3.3 PP

As defined in 10.1.3.6/V.34.

8.3.4 S

As defined in 10.1.3.7/V.34.

8.3.5 SCR

Signal SCR is defined as binary ones modulated according to 10.1.3.9/V.34 except that neither the scrambler nor the differential encoder need be initialized at the beginning of its transmission. During Phase 3 and Phase 4 start-up procedures the constellation size depends on bit 47 of J_d. During rate renegotiation procedures the constellation size depends on bit 48 of J_d.

8.3.6 TRN

As defined in 10.1.3.8/V.34 using a 4-point 2D constellation.

8.4 Phase 3 signals for the digital modem

The digital modem shall use the polynomial, GPC, in equation 7-1/V.34 when generating signals J_d, J'_d and TRN_{1d}. Signals transmitted by the digital modem during Phase 3 are not spectrally shaped.

8.4.1 DIL

The parameters necessary for the digital modem to form the DIL are sent to it by the analogue modem using the DIL descriptor defined in 8.3.1.

The DIL consists of N DIL-segments of length L_c where:

$$0 \le N \le 255;$$

$$1 \le c \le 8; \text{ and}$$

$$L_c = (H_c + 1) * 6 \text{ symbols.}$$

Eight H_c values are used to calculate the length of the DIL-segments containing training symbols from each Uchord. H_1 shall be used to calculate the length of the DIL-segments containing training symbols from $Uchord_1$, H_8 shall be used to calculate the length of the DIL-segments containing training symbols from $Uchord_8$.

Eight Ucodes, REF_c, define the PCM codeword used as a reference symbol in DIL-segments containing training symbols from each Uchord. The PCM codeword given by the Ucode REF_1 shall be used as a reference symbol in DIL-segments containing training symbols from $Uchord_1$, the PCM codeword given by the Ucode REF_8 shall be used as a reference symbol in DIL-segments containing training symbols from $Uchord_8$.

A single Sign Pattern (SP) and Training Pattern (TP) is used for the entire DIL. An SP bit determines the sign of a transmitted symbol. 0 shall represent negative and 1 shall represent positive. A TP bit determines whether the reference symbol (REF_c) or a training symbol is transmitted. 0 shall represent REF_c and 1 shall represent a training symbol. The LSB of each pattern applies to the first symbol of a DIL-segment. The lengths of these patterns are:

$$1 \le L_{SP} \le 128; \text{ and}$$

$$1 \le L_{TP} \le 128.$$

The patterns are restarted at the beginning of each DIL-segment. The patterns are repeated independently within DIL-segments whose lengths exceed that of L_{SP} or L_{TP}.

The entire sequence, not just the last DIL-segment, is repeated until either the analogue modem causes it to be terminated or a timeout occurs. The sequence shall be terminated on a DIL-segment boundary.

A set of N Ucodes determine the training symbol that is assigned to each DIL-segment. The first of the N Ucodes specifies the training symbol assigned to the first DIL-segment and so on.

When N = 0, DIL is not transmitted.

8.4.2 J_d

Sequence J_d consists of a whole number of repetitions of the bit pattern given in Table 13. Bit 0 is transmitted first. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO}. A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted TRN_{1d}.

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 13/V.90 – Definition of bits in J_d

J_d bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18:33	Data signalling rate capability mask. Bit 18:28 000; bit 19:29 333; bit 20:30 666; …; bit 33:48 000. Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the digital modem
34	Start bit: 0
35:46	Data signalling rate capability mask (contd.). Bit 35:49 333; bit 36:50 666; …; bit 39:54 666; bit 40:56 000; bits 41 to 46: Reserved for ITU. (These bits are set to 0 by the digital modem and are not interpreted by the analogue modem.) Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the digital modem
47	Size of constellation used to transmit CP, E and SCR during training sequences: 0 = 4-point constellation; 1 = 16-point constellation
48	Size of constellation used to transmit CP, E and SCR during rate renegotiation procedures: 0 = 4-point constellation; 1 = 16-point constellation
49:50	A number between 1 and 3 indicating the digital modem's maximum lookahead for spectral shaping
51	Start bit: 0
52:67	CRC
68:71	Fill bits: 0000

8.4.3 J'_d

J'_d is used to terminate J_d. J'_d consists of 12 binary zeroes. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO}. A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted J_d.

8.4.4 S_d

S_d consists of 64 repetitions of the sequence {+W, +0, +W, –W, –0, –W} where W is defined to be the PCM codeword whose Ucode is 16 + U_{INFO} and 0 is the PCM codeword with Ucode 0. $\overline{S_d}$ consists of 8 repetitions of the sequence {–W, –0, –W, +W, +0, +W}.

The first symbol of $\overline{S_d}$ is defined to be transmitted in data frame interval 0. The digital modem shall keep data frame alignment from this point on.

8.4.5 TRN_{1d}

Signal TRN_{1d} is a sequence of the PCM codeword whose Ucode is U_{INFO} with signs generated by applying binary ones to the input of the scrambler described in 5.3. A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The scrambler is initialized to zero prior to the transmission of TRN_{1d}. TRN_{1d} shall be an integer multiple of 6 symbols long.

8.5 Phase 4 signals for the analogue modem

8.5.1 B1

As defined in 10.1.3.1/V.34.

8.5.2 CP

CP sequences consist of symbols chosen from a 4- or 16-point 2D constellation. During Phase 4 start-up procedures the constellation size depends on bit 47 of J_d. During rate renegotiation procedures the constellation size depends on bit 48 of J_d. CP is used by the analogue modem to pass constellation parameters to the digital modem. A CP_t sequence is sent to pass the parameters used by the digital modem in Phase 4 training. A CP sequence with the acknowledge bit set to 1 is denoted by CP′. A CP sequence with the request for silence bit set is denoted CP_s. Due to the nature of the procedures that use CP_s, the constellation parameters contained in CP_s are not used. The average power of the constellations that the analogue modem requests the digital modem to use during data mode shall not be greater than 3 dB above the average power of the constellations it requests the digital modem to use during Phase 4.

CP sequences are modulated according to 10.1.3.9/V.34. The scrambler and differential encoder are initialized to zero prior to the transmission of the first CP_t sequence. Bit fields for CP sequences are defined in Table 14. Bit 0 is transmitted first.

The CRC generator used is described in 10.1.2.3.2/V.34.

CP sequences are defined to be of variable length. A constellation mask consists of 128 bits where a bit set to 1 indicates that the constellation includes the PCM code represented by the corresponding Ucode. Only the number of different constellations need to be sent. The constellations that are sent are indexed from 0 (in bits 136:271) to a maximum of 5 (in bits 816:951). If the constellations at the digital modem's transmitter differ from those at the output to the codec's D/A convertor, then bit 128 shall be set and the constellation at the output to the codec's D/A convertor corresponding to each transmit constellation shall be sent. Due to the variability in the number of constellations, a parameter γ is defined to be 136* (the maximum constellation index given in bits 103:127) and a parameter δ is defined to be $(2^*\gamma)+136$ if bit 128 is set and γ if bit 128 is clear.

When multiple CP and CP′ sequences are transmitted as a group, they shall all contain identical modulation and spectral shaping parameter information.

Table 14/V.90 – Definition of bits in CP

CP bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
19	0 indicates CP_t; 1 indicates CP
20:24	Selected digital modem to analogue modem data signalling rate, an integer, drn, between 0 and 22. drn = 0 indicates cleardown. Data signalling rate = (drn+20)*8000/6 in CP and (drn+8)*8000/6 in CP_t.
25:29	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
30	Set to 1 indicates a silent period is requested. This may be used during rate renegotiation (see 9.6)
31:32	S_r: The number of sign bits used as redundancy for spectral shaping
33	Acknowledge bit: 0 = modem has not received MP from far end; 1 = received MP from far end
34	Start bit: 0
35	Codec type: 0 = μ-law; 1 = A-law
36:48	Analogue modem to digital modem data signalling rate capability mask: Bit 36:4800; …; bit 47:31 200; bit 48:33 600. Bits set to 1 indicate data signalling rates supported and enabled in analogue modem transmitter
49:50	ld: Number of look-ahead frames requested during spectral shaping. This shall be consistent with the capabilities of the digital modem indicated in J_d
51	Start bit: 0
52:67	The RMS value of TRN_{1d} at the transmitter output divided by the RMS value of TRN_{1d} at the output to the codec's D/A convertor expressed in unsigned Q3.13 format (xxx.xxxxxxxxxxxxx)
68	Start bit: 0
69:76	Parameter a_1 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
77:84	Parameter a_2 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
85	Start bit: 0
86:93	Parameter b_1 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
94:101	Parameter b_2 of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
102	Start bit: 0
103:106	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 0
107:110	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 1
111:114	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 2
115:118	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 3
119	Start bit: 0
120:123	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 4
124:127	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 5
128	Set to 1 if the constellations at the transmitter differ from those at the output to the codec's D/A convertor

Table 14/V.90 – Definition of bits in CP *(concluded)*

CP bits LSB:MSB	Definition
129:135	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
136	Start bit: 0
137:152	Constellation mask for Uchord_1 (bit 137 corresponds to Ucode 0)
153	Start bit: 0
154:169	Constellation mask for Uchord_2 (bit 154 corresponds to Ucode 16)
170	Start bit: 0
171:186	Constellation mask for Uchord_3 (bit 171 corresponds to Ucode 32)
187	Start bit: 0
188:203	Constellation mask for Uchord_4 (bit 188 corresponds to Ucode 48)
204	Start bit: 0
205:220	Constellation mask for Uchord_5 (bit 205 corresponds to Ucode 64)
221	Start bit: 0
222:237	Constellation mask for Uchord_6 (bit 222 corresponds to Ucode 80)
238	Start bit: 0
239:254	Constellation mask for Uchord_7 (bit 239 corresponds to Ucode 96)
255	Start bit: 0
256:271	Constellation mask for Uchord_8 (bit 256 corresponds to Ucode 112)
272:271+γ	Possibly more constellations in same format as bits 136:271
272+γ:271+δ	Corresponding codec constellations in same format as bits 136:271
272+δ	Start bit: 0
273+δ:288+δ	CRC
289+δ:291+δ	Fill bits: 000

The analogue modem shall design constellations such that their average power, when calculated using the formula below, does not exceed the limit given in Table 15 corresponding to the maximum digital modem transmit power specified in INFO_{0d}, assuming the calculation is performed using infinite precision arithmetic.

$$\text{Average power of constellation set} = \frac{\sum_{i=0}^{5} \sum_{j=0}^{M_i-1} p_{i,j} \cdot n_{i,j}}{6 \cdot 2^K}$$

where K is defined in 5.4.1;

M_i is defined in 5.4.3;

$p_{i,j}$ is the square of the linear value in Table 1 corresponding to the level labelled j in the i^{th} constellation at the measurement point specified by bit 38 of INFO_{0d}; and

$$n_{i,j} = A_i(R_{i+1} + 1) \qquad \text{if } j < K_i$$

$$n_{i,j} = 2^K - A_i(R_i - R_{i+1}) \qquad \text{if } j = K_i$$

$$n_{i,j} = A_i(R_{i+1}) \qquad \text{if } j > K_i$$

where $A_0 = 1$; $A_{i+1} = A_i M_i$; and R_i and K_i are the outputs of the modulus encoder when $R_0 = 2^K - 1$ in 5.4.3.

Table 15/V.90 – Limits for the average power calculation

Maximum digital modem transmit power, dBm0	Limit of average power calculation
–0.5	$(15124)^2$
–1	$(14276)^2$
–1.5	$(13480)^2$
–2	$(12724)^2$
–2.5	$(12012)^2$
–3	$(11340)^2$
–3.5	$(10708)^2$
–4	$(10108)^2$
–4.5	$(9544)^2$
–5	$(9008)^2$
–5.5	$(8504)^2$
–6	$(8028)^2$
–6.5	$(7580)^2$
–7	$(7156)^2$
–7.5	$(6756)^2$
–8	$(6380)^2$
–8.5	$(6020)^2$
–9	$(5684)^2$
–9.5	$(5368)^2$
–10	$(5068)^2$
–10.5	$(4784)^2$
–11	$(4516)^2$
–11.5	$(4264)^2$
–12	$(4024)^2$
–12.5	$(3800)^2$
–13	$(3588)^2$
–13.5	$(3388)^2$
–14	$(3196)^2$
–14.5	$(3020)^2$
–15	$(2852)^2$
–15.5	$(2692)^2$
–16	$(2540)^2$

NOTE – Since modems use finite precision arithmetic, the digital modem should ensure that its calculations give results greater than or equal to the results that would be calculated using infinite precision arithmetic. Similarly, the analogue modem should ensure that its calculations give results less than or equal to the results that would be calculated using infinite precision arithmetic. The actions that a digital modem takes when a constellation set is found to have an average power above the appropriate limit are a national matter and are beyond the scope of this Recommendation.

8.5.3 E

As defined in 10.1.3.2/V.34.

8.6 Phase 4 signals for the digital modem

Signals transmitted by the digital modem during Phase 4 may be spectrally shaped. During initial train or retrain, signals TRN_{2d}, MP and E_d use the spectral shaping parameters defined by CP_t. During rate renegotiation, TRN_{2d}, MP and E_d use the spectral shaping parameters as used in the preceding data mode along with the K previously derived from CP_t. $B1_d$ and the following data mode signals shall use the spectral shaping parameters defined by CP.

8.6.1 $B1_d$

$B1_d$ consists of 48 data frames of scrambled ones transmitted at the end of start-up using the selected data mode constellation parameters. The scrambler, differential encoder and spectral shape filter memory are initialized to zero prior to transmitting $B1_d$. The symbols in the first data frame of $B1_d$ shall have the magnitudes resulting from mapping the first D scrambled ones after initializing the scrambler to zero, and shall be identical for all values of ld. Permitted values of K and S are given in Table 2.

8.6.2 E_d

E_d consists of 2 data frames of scrambled binary zeroes used to signal the end of MP. It is mapped using the same constellation parameters used to send TRN_{2d}.

8.6.3 MP

Modulation parameters for the analogue modem are sent in an MP sequence. MP is transmitted using the constellation parameters used to send TRN_{2d}. An MP with the acknowledge bit set is denoted MP′. Bit fields for MP sequences are defined in Table 16. Bit 0 is transmitted first.

Two types of MP sequences are used. Type 1 is the same as Type 0 with the addition of precoding coefficients. The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple MP and MP′ sequences are transmitted as a group, they shall all contain identical modulation parameter information.

Table 16/V.90 – Definition of bits in MP

MP bits LSB:MSB	Definition
0:16	Frame Sync: 11111111111111111
17	Start bit: 0
18	MP Type bit: 0 = Type 0 without precoder coefficients; 1 = Type 1 with precoder coefficients
19:23	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
24:27	Maximum analogue modem to digital modem data signalling rate, drn. Data rate = drn*2400 where drn is an integer between 2 and 14. drn = 0 indicates cleardown
28	Reserved for ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
29:30	Trellis encoder select bits in analogue modem to digital modem direction: 0 = 16 state; 1 = 32 state; 2 = 64 state; 3 = reserved The digital modem receiver requires the analogue modem transmitter to use the selected trellis encoder
31	Nonlinear encoder parameter select bit for the analogue modem transmitter. 0: $\Theta = 0$; 1: $\Theta = 0.3125$
32	Constellation shaping select bit for the analogue modem transmitter. 0: minimum; 1: expanded (see Table 10/V.34)
33	Acknowledge bit: 0 = modem has not received CP from far end; 1 = received CP from far end
34	Start bit: 0
35	Reserved for ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
36:49	Analogue modem to digital modem data signalling rate capability mask: Bit 36:4800; ...; bit 47:31 200; bit 48:33 600; 49: Reserved for ITU. (This bit is set to 0 by the digital modem and is not interpreted by the analogue modem.) Bits set to 1 indicate data signalling rates supported and enabled in digital modem
50	Reserved for ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
51	Start bit: 0

Table 16/V.90 – Definition of bits in MP *(concluded)*

MP bits LSB:MSB	Definition
	Continuation for MP Type 0 (without precoder coefficients)
52:67	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
68	Start bit: 0
69:84	CRC
85	Fill bit: 0
86:…	Fill bits: 0s to extend the MP sequence length to the next multiple of 6 symbols
	Continuation for MP Type 1 (with precoder coefficients)
52:67	Precoding coefficient h(1) real
68	Start bit: 0
69:84	Precoding coefficient h(1) imaginary
85	Start bit: 0
86:101	Precoding coefficient h(2) real
102	Start bit: 0
103:118	Precoding coefficient h(2) imaginary
119	Start bit: 0
120:135	Precoding coefficient h(3) real
136	Start bit: 0
137:152	Precoding coefficient h(3) imaginary
153	Start bit: 0
154:169	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
170	Start bit: 0
171:186	CRC
187	Fill bit: 0
188:…	Fill bits: 0s to extend the MP sequence length to the next multiple of 6 symbols

8.6.4 R

Signal R is transmitted by repeating the 6 symbol sequence containing PCM codewords with the sign pattern + + + – – – where the left-most sign is transmitted first. $\overline{\mathrm{R}}$ consists of 4 repetitions of the 6-symbol sequence containing the same PCM codewords with the sign pattern – – – + + + where the left-most sign is transmitted first.

NOTE – Neither R nor $\overline{\mathrm{R}}$ are differentially encoded. This imposes a requirement on the receiver to be able to detect these sequences regardless of their polarity.

R_d denotes signal R using the highest power PCM codeword from the data mode constellation of each data frame interval as passed in CP.

R_i denotes signal R using the single PCM codeword whose Ucode is U_{INFO} for all data frame intervals.

R_t denotes signal R using the highest power PCM codeword from the training constellation of each data frame interval as passed in CP_t.

8.6.5 TRN_{2d}

TRN_{2d} is generated by applying scrambled binary ones to the encoder of 5.4. The constellation set to be used is passed in CP_t. The scrambler, differential encoder and spectral shape filter memory shall be initialized to zero prior to transmitting TRN_{2d}. The symbols in the first data frame of TRN_{2d} shall have the magnitudes resulting from mapping the first D scrambled ones after initializing the scrambler to zero, and shall be identical for all values of ld. Permitted values of K and S are given in Table 17. TRN_{2d} shall be an integer multiple of 6 symbols long.

Table 17/V.90 – Phase 4 signalling rate for different K and S

K, bits entering modulus encoder	S, sign bits used for Phase 4 data		Data Signalling Rate, kbit/s	
	From	To	From	To
6	3	6	12	16
7	3	6	13 1/3	17 1/3
8	3	6	14 2/3	18 2/3
9	3	6	16	20
10	3	6	17 1/3	21 1/3
11	3	6	18 2/3	22 2/3
12	3	6	20	24
13	3	6	21 1/3	25 1/3
14	3	6	22 2/3	26 2/3
15	3	6	24	28
16	3	6	25 1/3	29 1/3
17	3	6	26 2/3	30 2/3
18	3	6	28	32
19	3	6	29 1/3	33 1/3
20	3	6	30 2/3	34 2/3
21	3	6	32	36
22	3	6	33 1/3	37 1/3
23	3	6	34 2/3	38 2/3
24	3	6	36	40

9 Operating procedures

The start-up procedure carried out after establishing a dialled connection between the two modems consists of four distinct phases:

– Phase 1: Network interaction;

– Phase 2: Channel probing and ranging;

– Phase 3: Equaliser and echo canceller training and digital impairment learning;

– Phase 4: Final training.

9.1 Phase 1 – Network interaction

9.1.1 Use of bits in Recommendation V.8

Bit b5 in the "modn0" octet of Recommendation V.8 shall be set to indicate that a modem is capable of V.90 operation. This also indicates that at least one bit shall be set in the V.90 availability category. A modem that indicates V.90 capability shall indicate its PSTN access type using a bit in the PSTN access category. The operation defined in this Recommendation is only possible when two V.90 capable modems are connected and one or both of the modems is

accessing the PSTN digitally. If both modems are accessing the PSTN over analogue connections they shall proceed in accordance with Recommendation V.8 as if V.90 capability had not been indicated. Similarly, if the information in the V.90 availability category does not indicate the presence of an analogue and digital modem pair, the modems shall proceed in accordance with Recommendation V.8 as if V.90 capability had not been indicated. In the case where both modems are digitally connected to the PSTN and both modems indicate the ability to be an analogue and a digital modem, the call modem shall become the analogue modem and the answer modem shall become the digital modem.

9.1.2 Call modem

9.1.2.1 Initially, the call modem shall condition its receiver to detect either signal ANS or ANSam as defined in Recommendation V.8, and the modem shall either transmit CI, CT, CNG or no signal as defined in Recommendation V.8. If signal ANSam is detected, the modem shall transmit silence for the period T_e as specified in Recommendation V.8. The modem shall then condition its receiver to detect JM and shall send CM with the appropriate bits set to indicate that V.90 operation is desired. When a minimum of two identical JM sequences have been received, the modem shall complete the current CM octet and send CJ. After sending CJ, the modem shall transmit silence for 75 ± 5 ms and proceed with Phase 2. This procedure is shown in Figure 3.

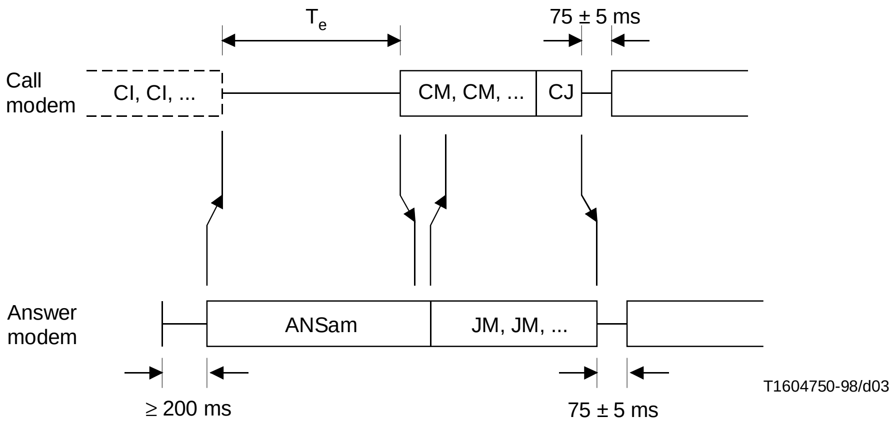

Figure 3/V.90 – Phase 1 – Network interaction

9.1.2.2 If signal ANS (rather than ANSam) is detected, the modem shall proceed in accordance with Annex A/V.32 *bis*, Recommendation T.30, or other appropriate Recommendations.

9.1.3 Answer modem

9.1.3.1 Upon connection to line, the modem shall initially remain silent for a minimum of 200 ms and then transmit signal ANSam according to the procedure specified in Recommendation V.8. This signal shall include phase reversals as specified in Recommendation V.8. The modem shall condition its receiver to detect CM and, possibly, calling modem responses specified in other appropriate Recommendations.

9.1.3.2 If a minimum of 2 identical CM sequences are received and the appropriate bits are set to indicate V.90 operation, the modem shall send JM and condition its receiver to detect CJ. After receiving all 3 octets of CJ, the modem shall transmit silence for 75 ± 5 ms, and proceed with Phase 2 of start-up. This procedure is shown in Figure 3.

9.1.3.3 If a call modem response specified in some other appropriate Recommendation is detected, the modem shall proceed in accordance with the appropriate Recommendation.

9.1.3.4 If neither CM nor a suitable call modem response is detected for the allowed ANSam transmission period as specified in Recommendation V.8, the modem shall transmit silence for 75 ± 5 ms, and then proceed in accordance with Annex A/V.32 *bis*, Recommendation T.30, or other appropriate Recommendations.

9.2 Phase 2 – Probing/ranging

Channel probing and ranging are performed in Phase 2 of the start-up procedure. The description below details both the error-free and recovery procedures in the digital and analogue modems. Capabilities information and modulation parameters are sent in the INFO sequences detailed in 8.2.3.

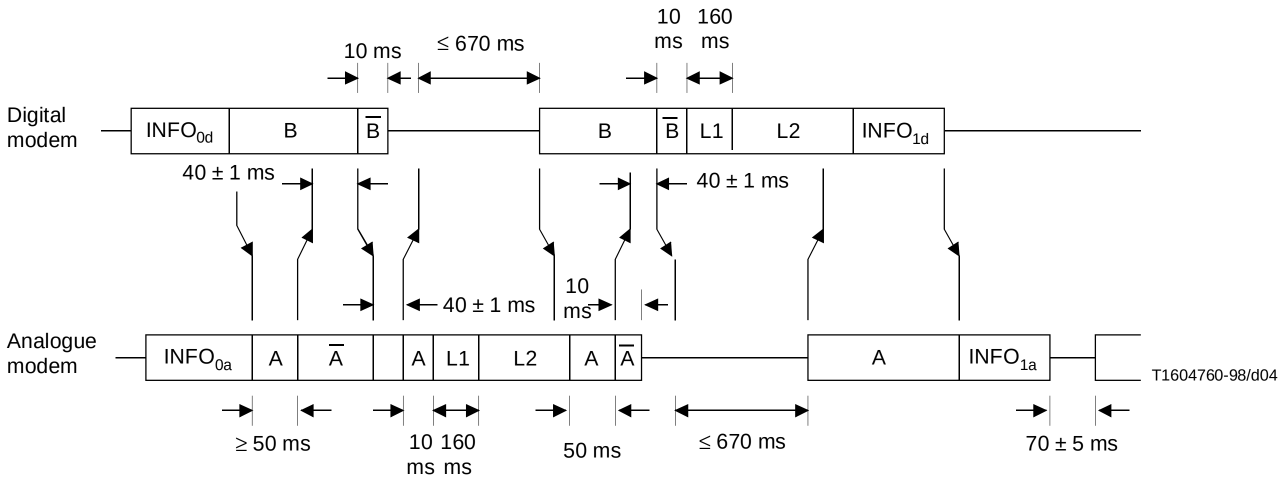

Figure 4/V.90 – Phase 2 – Probing/ranging

9.2.1 Digital modem

9.2.1.1 Error-free procedures

9.2.1.1.1 During the 75 ± 5 ms silent period ending Phase 1, the digital modem shall condition its receiver to receive $INFO_{0a}$ and detect Tone A. After the 75 ± 5 ms silent period, the digital modem shall send $INFO_{0d}$ with bit 28 set to 0, followed by Tone B.

9.2.1.1.2 After receiving $INFO_{0a}$, the digital modem shall condition its receiver to detect Tone A, receive $INFO_{0a}$ (see 9.2.1.2 Recovery procedures) and detect the subsequent Tone A phase reversal.

9.2.1.1.3 After detecting the Tone A phase reversal, the digital modem shall transmit a Tone B phase reversal. The Tone B phase reversal shall be delayed so that the time duration between receiving the Tone A phase reversal at the line terminals and the appearance of the Tone B phase reversal at the line terminals is 40 ± 1 ms. Tone B shall be transmitted for another 10 ms after the phase reversal. The digital modem shall then transmit silence and condition its receiver to detect a second Tone A phase reversal.

9.2.1.1.4 After detecting the second Tone A phase reversal, the digital modem has the information required to calculate the round-trip delay. The round-trip delay estimate, RTDEd, is the time interval between the appearance of the Tone B phase reversal at the digital modem line terminals and receiving the second Tone A phase reversal at the line terminals minus 40 ms. The modem shall then condition its receiver to receive the probing signals L1 and L2.

9.2.1.1.5 The digital modem shall receive signal L1 for its 160 ms duration. The digital modem may then receive signal L2 for a period of time not to exceed 500 ms. The digital modem shall then transmit Tone B and condition its receiver to detect Tone A and the subsequent Tone A phase reversal.

9.2.1.1.6 After detecting Tone A and the subsequent Tone A phase reversal, the digital modem shall transmit a Tone B phase reversal. The Tone B phase reversal shall be delayed so that the time duration between receiving the Tone A phase reversal at the line terminals and the appearance of the Tone B phase reversal at the line terminals is 40 ± 1 ms. Tone B shall be transmitted for an additional 10 ms after the phase reversal. The modem shall then transmit signal L1 followed by signal L2 and condition its receiver to detect Tone A.

9.2.1.1.7 After the digital modem detects Tone A and has received the local echo of L2 for a period of time not to exceed 550 ms plus a round-trip delay, the digital modem shall send $INFO_{1d}$.

9.2.1.1.8 After sending $INFO_{1d}$, the digital modem shall transmit silence and condition its receiver to receive $INFO_{1a}$. After receiving $INFO_{1a}$, the digital modem shall proceed to Phase 3 of the start-up procedure if bits 37:39 of $INFO_{1a}$ indicate the integer 6. If bits 37:39 of $INFO_{1a}$ indicate an integer between 0 and 5, the digital modem shall proceed in accordance with 11.3.1.1/V.34 assuming the role of a call modem. Any subsequent retrains shall use Phase 2 of V.90 regardless of the analogue modem's choice of operating mode.

9.2.1.2 Recovery procedures

9.2.1.2.1 If, in 9.2.1.1.2 or 9.2.1.1.3, the digital modem detects Tone A before receiving $INFO_{0a}$, or if it receives repeated $INFO_{0a}$ sequences, the digital modem shall repeatedly send $INFO_{0d}$ sequences. The digital modem shall set bit 28 of the $INFO_{0d}$ sequence to 1 after correctly receiving $INFO_{0a}$. If the digital modem receives $INFO_{0a}$ with bit 28 set to 1, it shall condition its receiver to detect Tone A and the subsequent Tone A phase reversal, complete sending the current $INFO_{0d}$ sequence, and then transmit Tone B. Alternatively, if the digital modem detects Tone A and has received $INFO_{0a}$, it shall condition its receiver to detect a Tone A phase reversal, complete sending the current $INFO_{0d}$ sequence, and transmit Tone B. In both cases, the digital modem shall then proceed according to 9.2.1.1.3.

9.2.1.2.2 If, in 9.2.1.1.3, the digital modem does not detect the Tone A phase reversal, the digital modem shall continue transmitting Tone B until it does detect a Tone A phase reversal.

9.2.1.2.3 If, in 9.2.1.1.4, the digital modem does not detect a Tone A phase reversal within 2000 ms from the phase reversal detected during the procedure in 9.2.1.1.3, the digital modem shall transmit silence and condition its receiver to detect Tone A. After detecting Tone A, the digital modem shall transmit Tone B and condition its receiver to detect a Tone A phase reversal and proceed in accordance with 9.2.1.1.3.

9.2.1.2.4 If, in 9.2.1.1.6, the digital modem does not detect the Tone A phase reversal within 900 ms plus a round-trip delay from the phase reversal detected during the procedure defined in 9.2.1.1.4, the modem waits 40 ms, then transmits a Tone B phase reversal. Tone B shall be transmitted for an additional 10 ms after the phase reversal. The modem shall then transmit signal L1 followed by signal L2, condition its receiver to detect Tone A, and proceed in accordance with 9.2.1.1.7.

9.2.1.2.5 If, in 9.2.1.1.7, the digital modem does not detect Tone A within 650 ms plus a round-trip delay from the beginning of L2, the digital modem shall initiate a retrain according to 9.5.1.1.

9.2.1.2.6 If, in 9.2.1.1.8, the digital modem does not receive $INFO_{1a}$ within 700 ms plus a round-trip delay from the end of $INFO_{1d}$ transmission, the digital modem shall condition its receiver to detect either Tone A or $INFOMARKS_a$. Upon detection of $INFOMARKS_a$, the digital modem shall either initiate a retrain according to 9.5.1.1 or send $INFO_{1d}$ and proceed in accordance with 9.2.1.1.8. Upon detection of Tone A, the digital modem shall respond to a retrain and proceed according to 9.5.1.2.

9.2.2 Analogue modem

9.2.2.1 Error-free procedures

9.2.2.1.1 During the 75 ± 5 ms silent period ending Phase 1, the analogue modem shall condition its receiver to receive $INFO_{0d}$ and detect Tone B. After the 75 ± 5 ms silent period, the analogue modem shall send $INFO_{0a}$ with bit 28 set to 0, followed by Tone A.

9.2.2.1.2 After receiving $INFO_{0d}$, the analogue modem shall condition its receiver to detect Tone B and receive $INFO_{0d}$ (see 9.2.2.2 Recovery procedures).

9.2.2.1.3 After Tone B is detected and Tone A has been transmitted for at least 50 ms, the analogue modem shall transmit a Tone A phase reversal, and condition its receiver to detect a Tone B phase reversal.

9.2.2.1.4 After detecting the Tone B phase reversal, the analogue modem has the information required to calculate the round-trip delay. The round-trip delay estimate, RTDEa, is the time interval between sending the Tone A phase reversal at the line terminals and receiving the Tone B phase reversal at the line terminals minus 40 ms.

9.2.2.1.5 The analogue modem shall then transmit a Tone A phase reversal. The Tone A phase reversal shall be delayed so that the time duration between receiving the Tone B phase reversal at the line terminals and the appearance of the Tone A phase reversal at the line terminals is 40 ± 1 ms. Tone A shall be transmitted for 10 ms after the phase reversal. Then the analogue modem shall transmit signal L1 followed by signal L2 and condition its receiver to detect Tone B.

9.2.2.1.6 When Tone B is detected and the analogue modem has received the local echo of L2 for a period of time not to exceed 550 ms plus a round-trip delay, the analogue modem shall transmit Tone A for 50 ms followed by a Tone A phase reversal. Tone A shall be transmitted for an additional 10 ms after the phase reversal. Then the analogue modem shall transmit silence and condition its receiver to detect a Tone B phase reversal.

9.2.2.1.7 After detecting the Tone B phase reversal, the analogue modem shall condition its receiver to receive the probing signals L1 and L2.

9.2.2.1.8 The analogue modem shall receive signal L1 for its 160 ms duration. The analogue modem may then receive signal L2 for a period of time not to exceed 500 ms. The analogue modem shall then transmit Tone A and condition its receiver to receive $INFO_{1d}$.

9.2.2.1.9 After receiving $INFO_{1d}$, the analogue modem shall send $INFO_{1a}$ using bits 37:39 to indicate its choice of V.90 mode or V.34 mode. After sending $INFO_{1a}$, the analogue modem shall proceed to either Phase 3 of the start-up procedure or 11.3.1.2/V.34 assuming the role of an answer modem. Any subsequent retrains shall use Phase 2 of V.90 regardless of the analogue modem's choice of operating mode.

9.2.2.2 Recovery procedures

9.2.2.2.1 If, in 9.2.2.1.2, 9.2.2.1.3, or 9.2.2.1.4, the analogue modem detects Tone B before correctly receiving $INFO_{0d}$, or if it receives repeated $INFO_{0d}$ sequences, the analogue modem shall repeatedly send $INFO_{0a}$. The analogue modem shall set bit 28 of the $INFO_{0a}$ sequence to 1 after correctly receiving $INFO_{0d}$. If the analogue modem receives $INFO_{0d}$ with bit 28 set to 1, it shall condition its receiver to detect Tone B, complete the current $INFO_{0a}$, and then transmit Tone A. Alternatively, if the analogue modem detects Tone B and has received $INFO_{0d}$, it shall complete the current $INFO_{0a}$, and transmit Tone A. In both cases, the analogue modem shall then proceed according to 9.2.2.1.3.

9.2.2.2.2 If, in 9.2.2.1.4, the analogue modem does not detect the Tone B phase reversal within 2000 ms, the analogue modem shall condition its receiver to detect Tone B and then proceed according to 9.2.2.1.3.

9.2.2.2.3 If, in 9.2.2.1.6, the analogue modem does not detect Tone B within 600 ms plus a round-trip delay from the beginning of L2, it shall condition its receiver to detect Tone B and transmit Tone A. It shall then proceed according to 9.2.2.1.3.

9.2.2.2.4 If, in 9.2.2.1.9, the analogue modem does not receive $INFO_{1d}$ within 2000 ms plus two round-trip delays from the detection of Tone B during the procedure defined in 9.2.2.1.6, the modem shall either initiate a retrain according to 9.5.2.1 or send $INFOMARKS_a$ until it receives $INFO_{1d}$ or detects Tone B. If Tone B is detected, the analogue modem shall proceed according to 9.2.2.1.3. If $INFO_{1d}$ is received, the analogue modem shall then proceed according to 9.2.2.1.9.

9.3 Phase 3 – Equaliser and echo canceller training and digital impairment learning

Equaliser and echo canceller training and digital impairment learning are performed in Phase 3 of the start-up procedure. The description below (see Figures 5 and 6) details the procedures in the digital and analogue modems.

9.3.1 Digital modem

The digital modem may initiate a retrain during Phase 3 according to 9.5.1.1. If Tone A is detected during Phase 3, the digital modem shall respond to retrain according to 9.5.1.2.

9.3.1.1 The digital modem shall be initially silent and condition its receiver to detect S and the subsequent $\overline{\mathrm{S}}$. If the duration of signal MD indicated by $INFO_{1a}$ is zero, the digital modem shall proceed according to 9.3.1.2. Otherwise, after detecting the $\mathrm{S\text{-}to\text{-}\overline{S}}$ transition, the digital modem shall wait for the duration of signal MD as indicated by $INFO_{1a}$ and then shall condition its receiver to receive signal S and the $\mathrm{S\text{-}to\text{-}\overline{S}}$ transition.

9.3.1.2 After detecting signal S and the $\mathrm{S\text{-}to\text{-}\overline{S}}$ transition, the digital modem shall condition its receiver to begin training its equaliser using signal PP. After receiving signal PP, the digital modem may further refine its equaliser using the first 512T of signal TRN.

9.3.1.3 After receiving the first 512T of signal TRN, the digital modem shall condition its receiver to receive sequence J_a. After receiving J_a, the digital modem may wait for up to 500 ms and shall then transmit signal $\mathrm{S_d}$ for 384T and signal $\overline{\mathrm{S_d}}$ for 48T.

9.3.1.4 The digital modem shall then transmit TRN_{1d} for a minimum of 2040T. Within 4000 ms of starting to transmit TRN_{1d} the digital modem shall transmit J_d and condition its receiver to detect signal S and the $\mathrm{S\text{-}to\text{-}\overline{S}}$ transition.

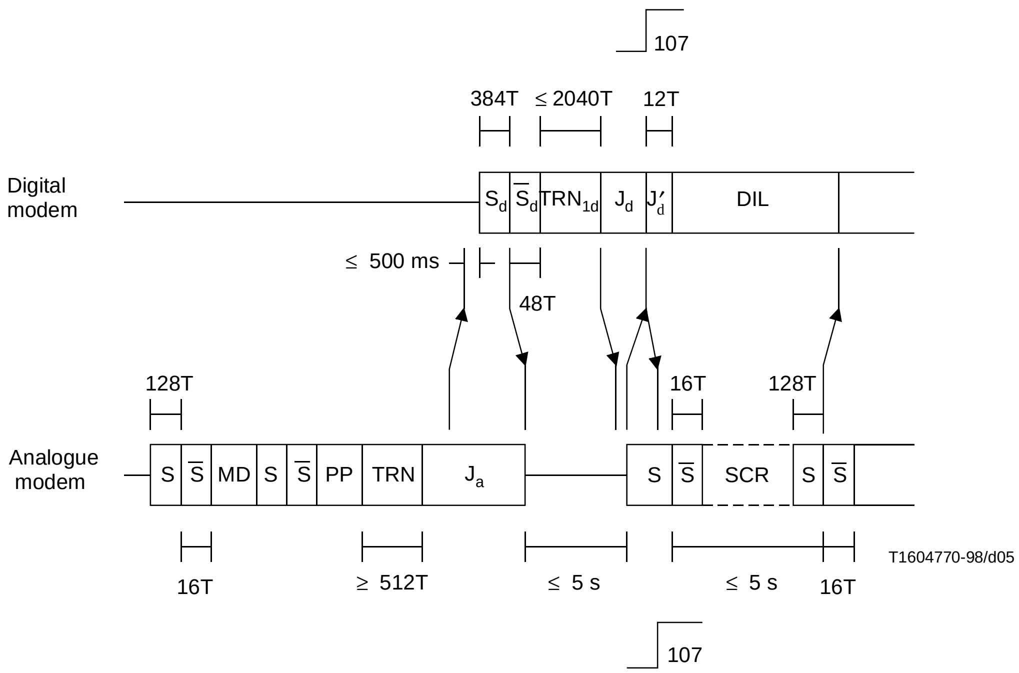

Figure 5/V.90 – Phase 3 – Equaliser and echo canceller training and digital impairment learning

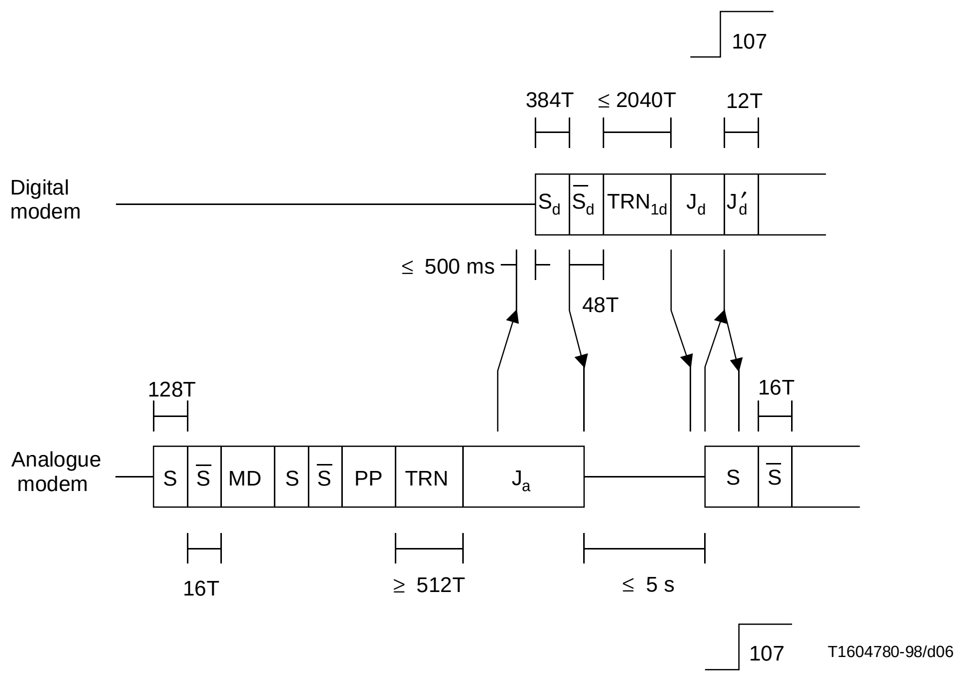

Figure 6/V.90 – Phase 3 – Equaliser and echo canceller training when no DIL has been requested

9.3.1.5 The digital modem shall continue to repeat the J_d sequence until it detects $\bar{S}$. It shall then complete the current J_d sequence and then transmit J'_d. If the digital modem does not detect $\bar{S}$ within 5100 ms plus a round-trip delay from the start of TRN_{1d}, it shall initiate a retrain according to 9.5.1.1. If the analogue modem has requested a DIL of length zero, the digital modem shall proceed to Phase 4 of the start-up procedure. Otherwise, the digital modem shall proceed according to 9.3.1.6.

9.3.1.6 The digital modem shall send the DIL requested by the analogue modem. After receiving a subsequent $S\text{-to-}\bar{S}$ transition, the digital modem shall complete sending the current segment of the DIL and proceed to Phase 4 of the start-up procedure.

NOTE – Since this Recommendation does not specify the turnaround time in the analogue modem from the J_d to J'_d transition to the $S\text{-to-}\bar{S}$ transition, failure by the digital modem to detect both $S\text{-to-}\bar{S}$ transitions may result in the premature termination of DIL.

9.3.2 Analogue modem

The analogue modem may initiate a retrain during Phase 3 according to 9.5.2.1. If Tone B is detected during Phase 3, the analogue modem shall respond to retrain according to 9.5.2.2.

9.3.2.1 After sending sequence $INFO_{1a}$, the analogue modem shall transmit silence for 70 ± 5 ms, signal S for 128T and signal $\bar{S}$ for 16T. If the duration of the analogue modem's MD signal, as indicated in the $INFO_{1a}$, is zero, the modem shall proceed according to 9.3.2.2. Otherwise, the modem shall transmit signal MD for the duration indicated in $INFO_{1a}$, signal S for 128T, and signal $\bar{S}$ for 16T.

9.3.2.2 The analogue modem shall then transmit signal PP.

9.3.2.3 After transmitting signal PP, the modem shall transmit signal TRN. Signal TRN consists of four constellation points and shall be transmitted for at least 512T. The total time from the beginning of transmission of signal MD to the end of signal TRN shall not exceed one round-trip delay plus 4000 ms.

9.3.2.4 After transmitting signal TRN, the modem shall send sequence J_a and condition its receiver to detect signal S_d and the $S_d\text{-to-}\overline{S_d}$ transition. After detecting the $S_d\text{-to-}\overline{S_d}$ transition, the modem shall terminate J_a and transmit silence. If the analogue modem does not detect the $S_d\text{-to-}\overline{S_d}$ transition within 1500 ms from the start of J_a, the analogue modem shall initiate a retrain according to 9.5.2.1.

9.3.2.5 The modem shall condition its receiver to begin its equaliser training using signal the first 2040T of signal TRN_{1d}.

9.3.2.6 After receiving the first 2040T of signal TRN_{1d}, the modem shall condition its receiver to receive sequence J_d.

9.3.2.7 After receiving J_d, the analogue modem may wait for up to 5000 ms from having begun to transmit silence as required in the procedure in 9.3.2.4 and shall then begin transmitting signal S and condition its receiver to detect J'_d. If the analogue modem does not receive J_d within 4500 ms from the end of J_a, the analogue modem shall initiate a retrain according to 9.5.2.1.

9.3.2.8 After detecting J'_d, the analogue modem shall transmit $\bar{S}$ for 16T. If the analogue modem requested a DIL of zero length it shall proceed with Phase 4 of the start-up procedure. Otherwise it shall proceed in accordance with 9.3.2.9.

9.3.2.9 The analogue modem shall receive the DIL sequence it requested in J_a. During the reception of DIL the analogue modem shall transmit either silence or SCR at its discretion.

9.3.2.10 Within 5000 ms of transmitting $\bar{S}$ in 9.3.2.8 the analogue modem shall again transmit signal S for 128T followed by $\bar{S}$ for 16T. This indicates to the digital modem that the analogue modem has received enough of the DIL sequence. The analogue modem shall then proceed to Phase 4 of the start-up procedure.

9.4 Phase 4 – Final training

See Figure 7.

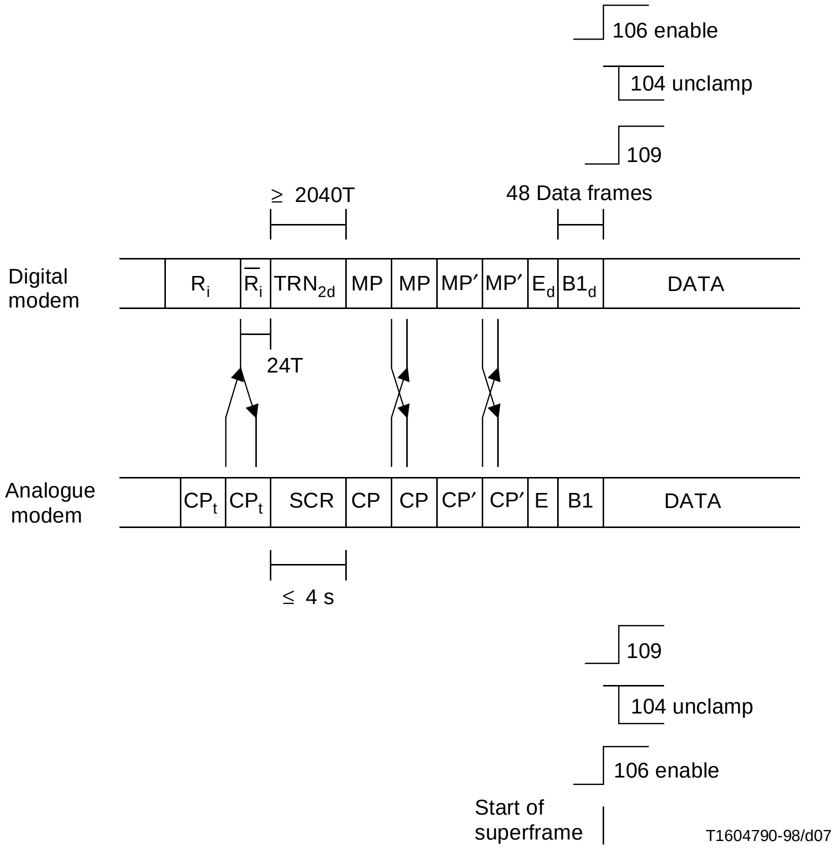

Figure 7/V.90 – Phase 4 – Final training

9.4.1 Digital modem

The digital modem shall initiate a retrain during Phase 4 according to 9.5.1.1 if it does not receive B1 within 15 s plus 5 round-trip delays after receiving $INFO_{1a}$ in 9.2.1.1.8. The digital modem may initiate a retrain at any time during Phase 4 according to 9.5.1.1. If Tone A is detected during Phase 4, the digital modem shall respond to retrain according to 9.5.1.2.

9.4.1.1 The digital modem shall send signal R_i for a minimum of 192T and condition its receiver to receive a CP_t sequence.

9.4.1.2 After receiving a CP_t sequence, the digital modem shall send signal $\overline{R_i}$ for 24T followed by TRN_{2d} for a minimum of 2040T.

9.4.1.3 Within 2000 ms of beginning to transmit TRN_{2d}, the digital modem shall send MP sequences. After receiving the analogue modem's CP sequence, the digital modem shall complete sending the current MP sequence, and then send MP′ sequences (MP sequences with the acknowledge bit set).

9.4.1.4 The digital modem shall continue sending MP sequences until it has sent an MP′ sequence and received a CP′ or a 20-bit E from the analogue modem. The digital modem shall then complete the current MP′ sequence and send a single E_d sequence.

9.4.1.5 After sending the E_d sequence, the digital modem shall send $B1_d$ at the negotiated data signalling rate using the data mode constellation parameters it received in CP. The modem shall then enable circuit 106 to respond to the condition of circuit 105 and begin data transmission using the modulation procedures of 5.4.

9.4.1.6 After receiving a 20-bit E sequence, the digital modem shall condition its receiver to receive B1. After receiving B1, the digital modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

9.4.2 Analogue modem

The analogue modem shall initiate a retrain during Phase 4 according to 9.5.2.1 if it does not receive $B1_d$ within 15 s plus 5 round-trip delays after sending $INFO_{1a}$ in 9.2.2.1.9. The analogue modem may initiate a retrain at any time during Phase 4 according to 9.5.2.1. If Tone B is detected during Phase 4, the analogue modem shall respond to retrain according to 9.5.2.2.

9.4.2.1 The analogue modem shall send CP_t sequences containing the constellation parameters that the digital modem shall use during Phase 4 training and rate renegotiations. The analogue modem shall also condition its receiver to detect an R_i-to-$\overline{R_i}$ transition.

9.4.2.2 After detecting an R_i-to-$\overline{R_i}$ transition, the analogue modem completes the current CP_t sequence and optionally transmits SCR for no more than 4000 ms.

9.4.2.3 The analogue modem shall send CP sequences containing the constellation parameters that the digital modem shall use during data mode. After receiving the digital modem's MP sequence, the analogue modem shall complete sending the current CP sequence, and then send CP′ sequences (CP sequences with the acknowledge bit set).

9.4.2.4 The analogue modem shall continue sending CP sequences until it has sent a CP′ sequence and received an MP′ or E_d from the digital modem. The analogue modem shall then complete the current CP′ sequence and send the 20-bit E sequence. The analogue modem shall condition its transmitter to transmit at a data signalling rate that is the maximum rate enabled in both modems that is less than or equal to the maximum analogue to digital modem data signalling rate specified in the MP sequence.

9.4.2.5 After sending the 20-bit E sequence, the analogue modem shall send B1 at the negotiated data signalling rate using the data mode modulation parameters. The analogue modem shall then enable circuit 106 to respond to the condition of circuit 105, start a new superframe, and begin data transmission using the modulation procedures of clause 6.

9.4.2.6 After receiving an E_d sequence, the analogue modem conditions its receiver to receive $B1_d$. After receiving $B1_d$, the analogue modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

9.5 Retrains

9.5.1 Digital modem

9.5.1.1 Initiating retrain

To initiate a retrain, the digital modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The digital modem shall then transmit Tone B and condition its receiver to detect Tone A. After detecting Tone A, the digital modem shall condition its receiver to detect a Tone A phase reversal and proceed in accordance with 9.2.1.1.3.

9.5.1.2 Responding to retrain

After detecting Tone A for more than 50 ms, the digital modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The digital modem shall then transmit Tone B, condition its receiver to detect a Tone A phase reversal, and proceed in accordance with 9.2.1.1.3.

9.5.2 Analogue modem

9.5.2.1 Initiating retrain

To initiate a retrain, the analogue modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The analogue modem shall then transmit Tone A and condition its receiver to detect Tone B. After detecting Tone B and when Tone A has been transmitted for at least 50 ms, the analogue modem shall transmit a Tone A phase reversal, condition its receiver to detect a Tone B phase reversal and proceed according to 9.2.2.1.4.

9.5.2.2 Responding to retrain

After detecting Tone B for more than 50 ms, the analogue modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The analogue modem shall then transmit Tone A and proceed in accordance with 9.2.2.1.3.

9.6 Rate renegotiation

The rate renegotiation procedure can be initiated at any time during data mode. Data signalling rate and spectral shaping parameters may change as a result of rate renegotiation. This procedure can also be used to retrain the analogue modem's echo canceller without going through a complete retrain. Only the analogue modem can request this second procedure.

The digital modem's transmitter and the analogue modem's receiver shall maintain data frame synchronization during rate renegotiation. Rate renegotiation shall be initiated by the digital modem's transmitter only on the boundary of a data frame. Similarly, a digital modem's transmitter shall only respond to a rate renegotiation on the boundary of a data frame.

9.6.1 Digital modem

The digital modem shall initiate a retrain according to 9.5.1.1 if it does not receive an E sequence within 5000 ms plus 2 round-trip delays after transmitting the R_d - to - $\overline{R_d}$ transition. The digital modem may initiate a retrain at any time during a rate renegotiation according to 9.5.1.1. If Tone A is detected during a rate renegotiation, the digital modem shall respond to retrain according to 9.5.1.2 (see Figure 8).

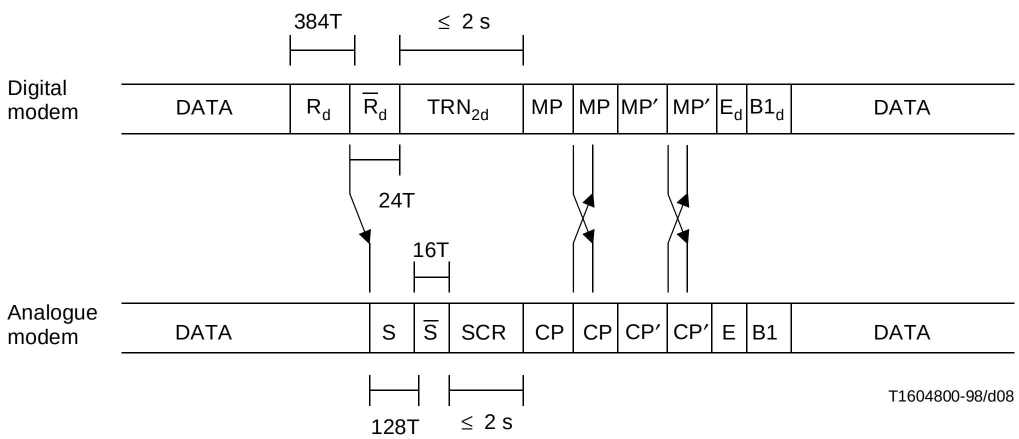

Figure 8/V.90 – Rate renegotiation procedure initiated by the digital modem

9.6.1.1 Initiating a rate renegotiation

9.6.1.1.1 The digital modem shall turn OFF circuit 106, condition its receiver to detect S, $\overline{S}$, and CP, and transmit signal R_d for 384T and $\overline{R_d}$ for 24T. The signal R_d shall begin on the boundary of a data frame. After transmitting $\overline{R_d}$, the digital modem shall optionally transmit TRN_{2d} for no more than 2000 ms followed by MP sequences and shall condition its receiver to receive CP sequences. The digital modem shall then proceed in accordance with 9.6.1.2.3.

9.6.1.2 Responding to a rate renegotiation

9.6.1.2.1 After detecting S, the digital modem shall clamp circuit 104 to binary one and condition its receiver to detect the S-to-$\overline{S}$ transition.

9.6.1.2.2 After detecting the S-to-$\overline{S}$ transition, the digital modem shall transmit signal R_d for 384T and $\overline{R_d}$, for 24T and condition its receiver to receive CP. The signal R_d shall begin on the boundary of a data frame. After transmitting $\overline{R_d}$, the digital modem shall optionally transmit TRN_{2d} for no more than 2000 ms followed by MP sequences.

9.6.1.2.3 After receiving a CP sequence, the digital modem shall send MP′ sequences and proceed in accordance with 9.4.1.4, unless bit 30 of the CP sequence is set (a CP_s sequence), in which case it proceeds in accordance with 9.6.1.2.4.

9.6.1.2.4 The digital modem shall transmit MP′ sequences until it receives a CP_s' sequence.

9.6.1.2.5 After receiving a CP_s' sequence, the digital modem shall complete sending the current MP′ and transmit E_d followed by silence. The digital modem shall generate silence by sending PCM codewords with magnitudes represented by Ucode 0. It shall retain data frame alignment during this period of silence.

9.6.1.2.6 After receiving a CP sequence with bit 30 clear, the digital modem shall transmit signal R_t for 384T and $\overline{R_t}$ for 24T. The signal R_t shall begin on the boundary of a data frame. The digital modem shall then start sending MP sequences and proceed in accordance with 9.4.1.4.

9.6.2 Analogue modem

The analogue modem shall initiate a retrain according to 9.5.2.1 if it does not receive E_d within 5000 ms plus 2 round-trip delays after sending the S-to-$\overline{S}$ transition. The analogue modem may initiate a retrain at any time during a rate renegotiation according to 9.5.2.1. If Tone B is detected during a rate renegotiation, the analogue modem shall respond to retrain according to 9.5.2.2 (see Figure 9).

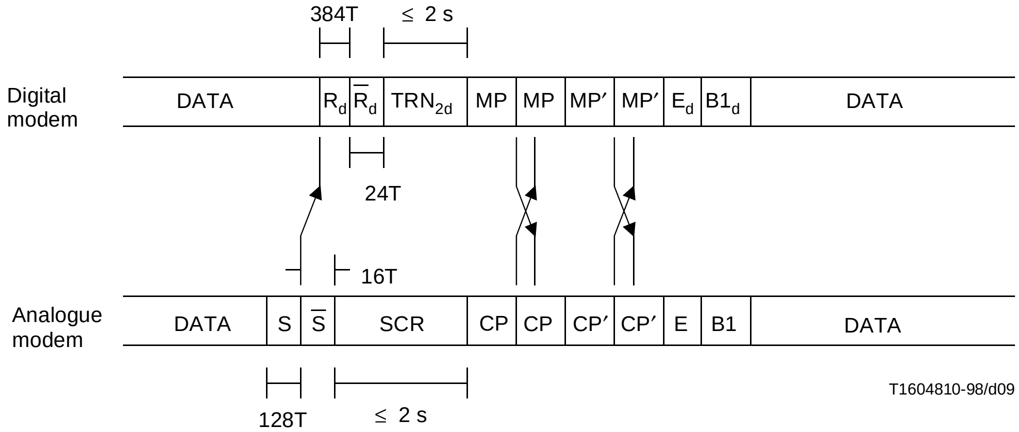

Figure 9/V.90 – Rate renegotiation initiated by the analogue modem

9.6.2.1 Initiating a rate renegotiation

9.6.2.1.1 The analogue modem shall turn OFF circuit 106, transmit signal S for 128T and condition its receiver to detect signal R_d and the R_d-to-$\overline{R_d}$ transition.

9.6.2.1.2 The analogue modem shall transmit signal $\overline{S}$ for 16T followed by an optional signal SCR for no more than 2000 ms.

9.6.2.1.3 The analogue modem shall then send CP sequences. If the analogue modem wishes to recondition its echo canceller, it shall send CP_s sequences.

9.6.2.1.4 After detecting the R_d-to-$\overline{R_d}$ transition, the analogue modem shall condition its receiver to receive MP sequences, continue transmitting CP and proceed in accordance with 9.4.2.3, unless it is sending a CP_s sequence, in which case it shall proceed in accordance with 9.6.2.1.5.

9.6.2.1.5 After receiving the digital modem's MP sequence, the analogue modem shall complete sending the current CP_s sequence, and then send CP'_s sequences (CP_s sequences with the acknowledge bit set).

9.6.2.1.6 After detecting E_d, the analogue modem shall complete sending the current CP'_s and send signal SCR until it has reconditioned its echo canceller, but for no more than 1000 ms.

9.6.2.1.7 The analogue modem shall send CP sequences with bit 30 clear and condition its receiver to detect signal R_t and the R_t-to-$\overline{R_t}$ transition.

9.6.2.1.8 After detecting the R_t-to-$\overline{R_t}$ transition, the analogue modem shall condition its receiver to receive MP sequences, continue transmitting CP and proceed in accordance with 9.4.2.3. (See Figure 10).

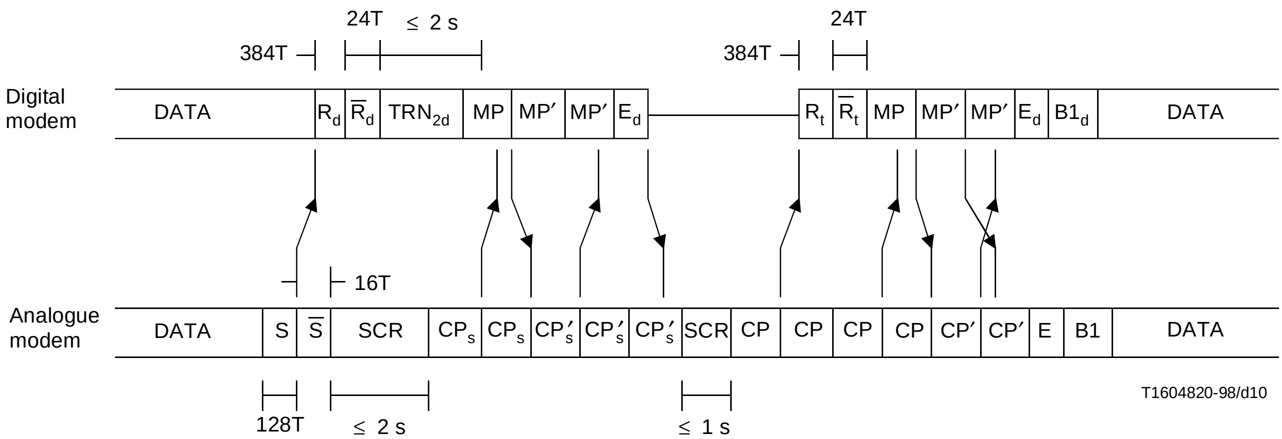

Figure 10/V.90 – Rate renegotiation initiated by the analogue modem with silence requested

9.6.2.2 Responding to a rate renegotiation

9.6.2.2.1 After receiving R_d, the analogue modem shall clamp circuit 104 to binary one and shall condition its receiver to detect the R_d-to-$\overline{R_d}$ transition.

9.6.2.2.2 After receiving the R_d-to-$\overline{R_d}$ transition, the analogue modem shall condition its receiver to receive MP, and transmit S for 128T.

9.6.2.2.3 The analogue modem shall then transmit $\overline{S}$ for 16T followed by an optional signal SCR for no more than 2000 ms.

9.6.2.2.4 The analogue modem shall then proceed in accordance with 9.6.2.1.3.

9.7 Cleardown

The cleardown procedure shall be used to terminate a connection. Cleardown is indicated by setting drn to 0 in either CP by the analogue modem or MP by the digital modem. This may be signalled at any time that a modem sends a rate sequence. To cleardown from data mode, a modem shall initiate a rate renegotiation according to 9.6 in order to send a rate sequence with drn = 0.

NOTE – The transmit and receive constellation fields of a CP sequence with drn = 0 should be ignored in the digital modem.

10 Testing facilities

Testing facilities as specified in other V-series modem Recommendations cannot be used for this Recommendation. Appropriate testing facilities are for further study.

11 Glossary

$\$_i$	Sign bits output from the spectral shaper
$\alpha, \beta, \gamma, \delta$	Variables used to define bit positions in J_a and CP
a_1, a_2	Parameters in the spectral shape filter
A_i	A parameter used to calculate $n_{i,j}$
b_0-b_{K-1}	The bits input to the modulus encoder
b_1, b_2	Parameters in the spectral shape filter
c	An index to each G.711 A-law or μ-law code segment
C_i	M_i PCM codes that make up the positive constellation points of data frame interval I
D	Total number of input data bits (K + S)
d_0-d_{D-1}	The input data bits
drn	A parameter used in determining the downstream data signalling rate
F(z)	The characteristic of the spectral shape filter
h()	A precoding coefficient
H_c	A parameter used in determining the length of a DIL-segment
i	The time index of the data frame interval, from 0 to 5
j	An index to a spectral shaping frame
j	A general index
K	The number of modulus encoder input data bits per data frame
k	A general index
K_i	The output of the modulus encoder used in data frame interval i
L_c	The length of a DIL-segment
ld	The look-ahead depth
L_{SP}	The length of SP
L_{TP}	The length of TP
M_i	Number of members of the PCM code set used in data frame interval i
n	A general index
N	The number of DIL-segments
$n_{i,j}$	A parameter related to the number of occurrences of a particular PCM code
$p_j'(k)$	A differentially encoded intermediate bit in the spectral shaper
PCM_i	A signed PCM codeword
$p_i(k)$	An input bit to the spectral shaper
$p_{i,j}$	A parameter related to the power of a particular PCM code
Q_j	The state of the trellis used in the spectral shaper
R_0	The integer formed for input to the modulus encoder
REF_c	A reference PCM codeword
R_{i+1}	Quotients Remainders generated during modulus encoding

S	The number of spectral shaper input data bits per data frame
s_0-s_{S-1}	The bits input to the spectral shaper
SP	A sign pattern
S_r	The number of PCM code sign bits per data frame used as redundancy for spectral shaping
T(z)	The transfer function of the spectral shape filter
$t_j(k)$	An intermediate bit in the spectral shaper
TP	A training pattern
U_i	The constellation point labelled by K_i
v[n]	The output of the spectral shape filter
W	A PCM codeword used in signal S_d
w[n]	The spectral shaping metric
x[n]	The spectral shape filter input
y[n]	An intermediate value in the spectral shaping metric calculation
z	A general index

Appendix I

Overview

Unlike previous modem Recommendations, this Recommendation defines a method for signalling between a modem connected to an analogue loop (the analogue modem) and a modem connected to a digital trunk (the digital modem). Although analogue modem Recommendations, such as V.34, have been implemented in this fashion for many years, this Recommendation takes advantage of this particular arrangement to increase the data signalling rate from the digital modem towards the analogue modem. The signalling method in this direction is a newly defined baseband scheme that utilizes the frequency band from 0 to 4 kHz. This Recommendation allows for spectral shaping to be employed to help the analogue modem combat the effects of the transformers and filters used in the digital-to-analogue conversion. Since this is for the benefit of the analogue modem, it is the analogue modem that requests the spectral shaping parameters to be used and so the optimum spectral shape is implementation dependent. In the direction from the analogue modem towards the digital modem, standard V.34 techniques are employed with the usual transmit and receive level considerations. An example network configuration is shown in Figure I.1.

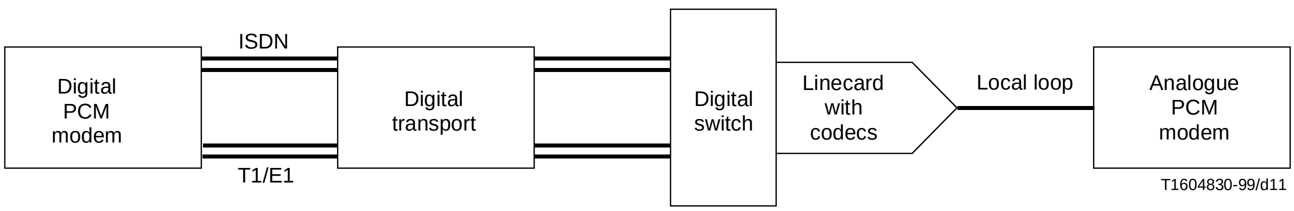

Figure I.1/V.90 – Example network configuration

EXHIBIT O

088

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Committee TR.30.1

Telecommunications Industry Association (TIA)

Location: Orlndo, FL Date: Dec 4-5, 1996

COMMITTEE CONTRIBUTION
Technical Committee TR-30 Meetings

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TITLE: Proposed Baseline for PCM Upstream

PROJECT: (PN 3838)

DISTRIBUTION: Members of TR-30.1and meeting attendees

ABSTRACT

Discussions during the Irvine meeting of the TR30.1 Ad-Hoc group on PCM modems resulted in an invitation to propose a baseline text for the use of PCM in the upstream direction in the Orlando meeting. This document contains such a proposal.

Copyright Statement

Intellectual Property Statement

The individual preparing this contribution knows of patents, the use of which may be essential to a standard resulting in whole or in part from this contribution.

Introduction:

Contribution Irvine-9 presented in the November '96 meeting of the PCM modem Ad-hoc group of TR30.1 proposed the use of PCM transmission in the upstream direction and provided supporting arguments. As a result of the discussion of that document, contributions were invited to propose a baseline for this approach during the December '96 meeting. This document contains a proposed baseline for the upstream data transmission in PCM modems.

Proposal:

1. *Phase III Training.*

1.1 Discussion

High speed operation in the upstream direction is made possible by the elimination of quantization noise. This in turn requires that most of the equalization be performed in the transmitter of the analog PCM modem. This is similar to the incorporation of the precoder in the V.34 transmitter. As in the V.34 case, taps trained in the receiver of the digital PCM modem will be transmitted back to the analog modem in an INFO sequence.

It is possible for the digital modem to train a model of the impulse response of the channel ("channel model") from the analog modem transmitter to the network A/D converter or directly train an equalizer provided that the form of the pre-equalizer is standardized as in the case of the V.34 precoder. One potential advantage of having the digital modem directly train the equalizer is that this would partition the training effort more equally between the analog and digital PCM modems since the analog modem has to train its own receiver equalizer in addition. Although it is not negligible, this advantage has become far less significant with the availability of more powerful processors. On the other hand, having the digital modem train the channel model and transmit its taps back to the analog PCM modem offers a significant practical advantage in that the pre-equalizer does not need to be standardized. With this approach, the treatment of the analog modem transmitter pre-equalizer can parallel the receiver equalizer very closely. In fact, the modem designer will have more flexibility in the treatment of some aspects of the transmitter pre-equalizer such as spectral shaping than the case at hand with the receiver. Bit to symbol mapping would be the only standardization effort required for the upstream direction. For these reasons, we propose the use of channel model training in the digital modem.

1.2 Proposed Baseline Text:

pseudo-random signal digital side

x.1 Modem Training

Training of the upstream channel will immediately follow the training of the downstream channel as shown in Figure x.1. The training signal PSA will be generated in the same manner as PSD as described in section y.1 and will equal the μ (or A) to linear converted version of PSD. It will consist of the sequence of samples x_n, $0 \le n < N_{PSA}$. The digital PCM modem will use the received version of the signal PSA denoted as a sequence of PCM samples Y_n, $0 \le n < N_{PSA}$, and use the μ (or A) to linear converted version of this sequence y_n, $0 \le n < N_{PSA}$ to calculate the optimal channel model coefficients c_k, $0 \le k < N_{UCM}$ and group delay d_{UCM} subject to the condition that the objective function defined as:

$$E_{UCM} = \Sigma_k \left(y_k - \Sigma_j c_j x_{k-j-d_{ucm}}\right)^2, \quad \{0 \le k < N_{PSA}, 0 \le j < N_{UCM}\}$$

μ-law code (linear levels)

$Y_n \rightarrow y_n$

y_n

GE 000939

is minimized with respect to c_k and d_{UCM} .

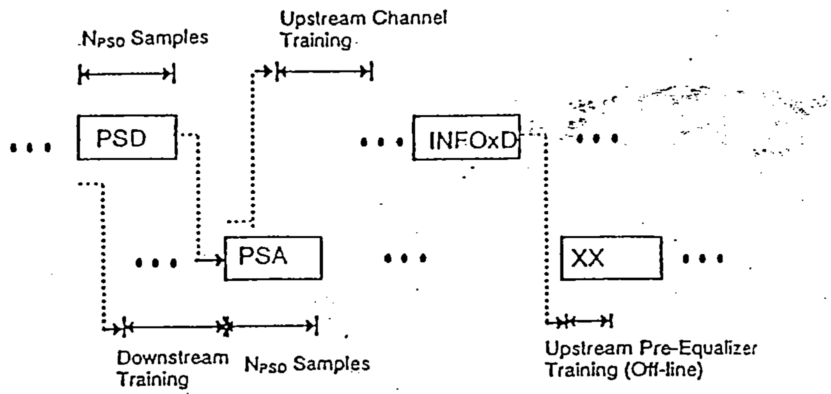

Figure x.1 Phase III modem training in the upstream direction

The calculated values of c_k and d_{UCM} will be transmitted to the analog PCM modem in the INFOxD sequence as indicated in Figure x.1 . The format of the INFOxD sequence is shown in Table x.1. The digital PCM modem will extract a 16 bit overall gain and transmit each channel coefficient after dividing with this gain value. The value of the gain chosen such that the information content of the 2 byte representation of all channel coefficients will be maximized. This gain value will be multiplied with 2^{15} and transmitted as an unsigned integer in octets p+1 and p+2 of the INFOxD sequence. The channel coefficients c_k will be multiplied with 2^{14} and sent as 2's complement signed integers in two bytes as indicated in Table x.1

Table x.1 Contents Of INFOxD sequence

...

Byte p+1

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	LS Byte Of Gain Value

Byte p+2

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	MS Byte Of Gain Value

Byte p+3

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	LS Byte Of Delay Value

Byte p+4

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	MS Byte Of Delay Value

Byte p+5

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	LS Byte Of Tap 0 of Channel Model

Byte p+6

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	MS Byte Of Tap 0 of Channel Model

Byte p+7

INFO0D bits (LSB:MSB)	Definition
xxxxxxxx	LS Byte Of Tap 1 of Channel Model

...

Byte $p+4+2*N_{UCM}$

INFOb0 bits (LSB:MSB)	$N_{UCM}-1$ Definition
xxxxxxxx	MS Byte Of Tap [redacted] of Channel Model [redacted]

2. *Constellation In The Upstream Direction*

2.1 Discussion

upstream & downstream

Contribution Irvine-9 presented that the two directions of transmission were similar and that the echo from the network hybrid was the main cause of the breakdown of the symmetry between the two directions. Focusing on the effects of the echo, it showed that a simple minded approach of treating the quantization noise of the echo signal as random noise would still allow the achievement of data rates up to 40 kbps in the upstream direction. Here as well, we separate the effects of the echo from the other challenges in the PCM modem, such as the DC null or non-linear distortion below 100 Hz, that apply equally to both directions of transmission. It is a valid question to ask whether if any of the remaining common challenges turns out to be intractable for the upstream direction. The answer to this question is implicit in the existence of practical systems in operation today.

Focusing on the effects of echo again, we complement the presentation of the 16 symbol constellation in Irvine-9 with a more comprehensive set of 8 , 16 and 32 symbol constellations presented here. Figures 1, 2 and 3 present, respectively, simulation results for the 32, 16 and 8 symbol cases that are directly comparable to Figure 3 of Irvine-9 for the 16 symbol constellation. The figures in a) correspond to an hybrid echo return loss of -10 dB which is at the worst end of typical hybrid characteristics. The figures in b) correspond to a conservative value of -15 dB and finally those in c) correspond to the more favorable value of -20 dB. Figure 3 corresponds to the worst case scenario of 0 dB echo return loss. The energy of the signal entering the pre-equalizer is indicated for each constellation in Table ~~x.2~~ x.1. The constellation to be used among these choices will be selected by the digital PCM modem and indicated to the analog PCM modem as

part of an INFO sequence in final phase of training. Since there is a small number of discrete possibilities, this indication can easily be done by indexing the different alternative constellations with an integer.

As can be seen in Table xx.1, the data rate emerges to be a function of the the echo return loss *and* the loop loss. Even for the worst case of echo return loss, it is possible to achieve 40 kbps as long as the loop loss is very small. When both echo and the loop loss are large, we would typically fall back to the 16 level constellation. We do not expect that the 8 level constellation will be needed, but include it here for completeness.

We have so far focused on the effects of echo and loop loss. Many issues that remain to be addressed for the downstream direction, such as minimizing the DC content of the transmitted signal spectrum apply equally to the upstream direction of transmission. Consequently, the details of the proposals presented here are expected to be modified based on the techniques agreed for addressing these challenges that apply to both directions. For example, either of the two approaches presented in Irvine-4 and Irvine-11 for spectral shaping (or another alternative) can be used in the upstream direction as well. If adopted, such an approach may require augmentation of the constellations given in Table xx.1 . This will not be a problem as indicated by the signal energy values in the table. Each of these constellations provide comfortable room for constellation expansion without approaching the transmission power limit of -9 dBm.

2.2 Proposed Baseline Text:

xx.1 Upstream Constellation selection

The digital PCM modem will select an upstream constellation based on the information available to it and indicate its selection in the INFOxxD sequence in the final phase of training. The INFOxxD sequence will contain the index of the constellation selected from Table xx.1 . The analog PCM modem will use this constellation in data mode.

Table xx.1 Upstream Constellations

Index	Size	Data Rate	Energy (dBm)	Positive Symbols
0	32	40	-16.9	11,22,31,38,44,49,53,57,61,64,67,70,73,76,79,83
1	32	40	-12	16,31,42,50,57,64,69,73,76,79,82,84,86,88,90,92
2	16	32	-22.1	16,32,40,48,53,57,61,65
3	8	24	-18.3	31,52,64,73

Conclusions

It is proposed that the text presented here be adopted as the baseline text for the upstream direction of transmission in the V.PCM interim standard.

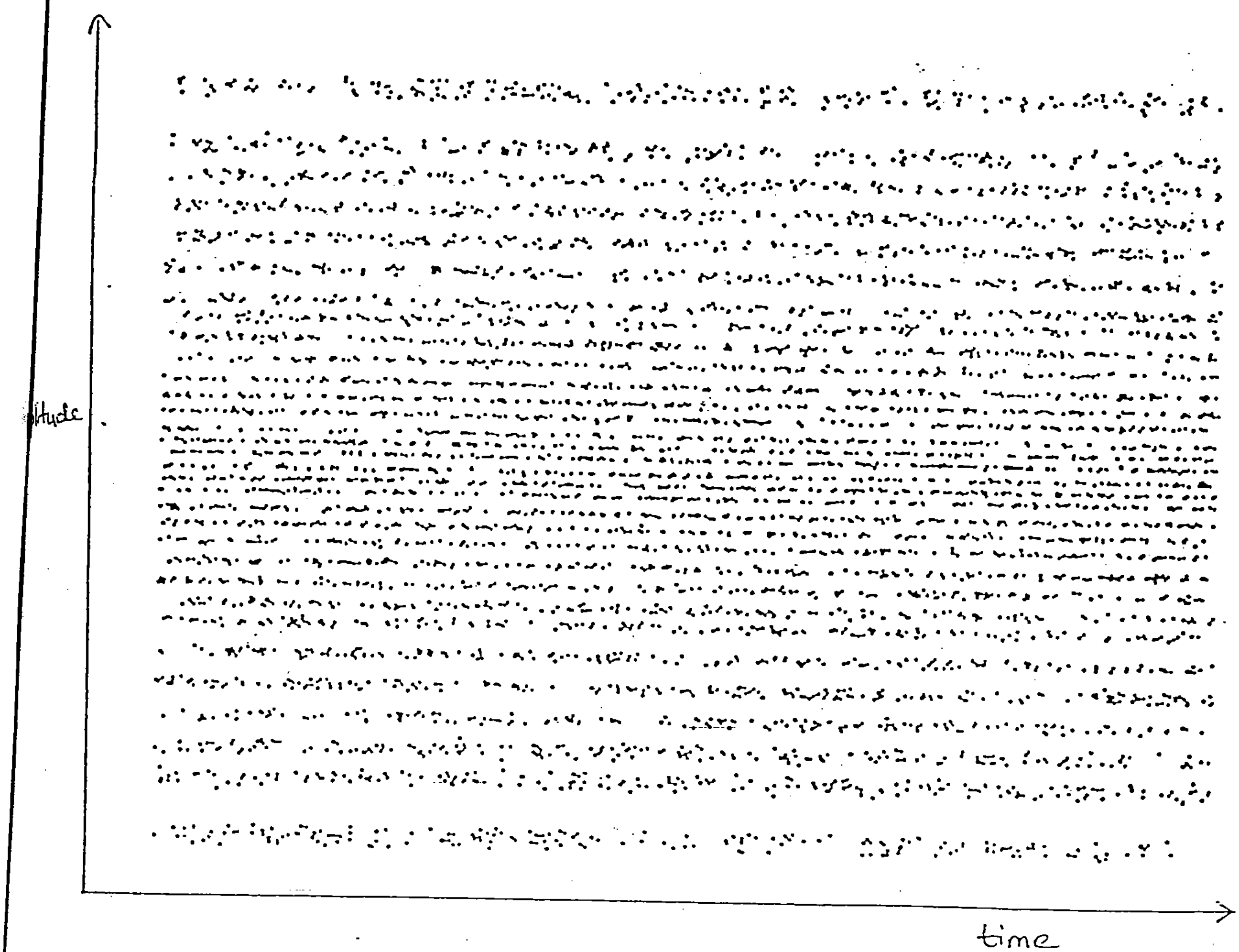

Figure 1 A)

Constellation: 0

Echo Return Loss: 20 dB

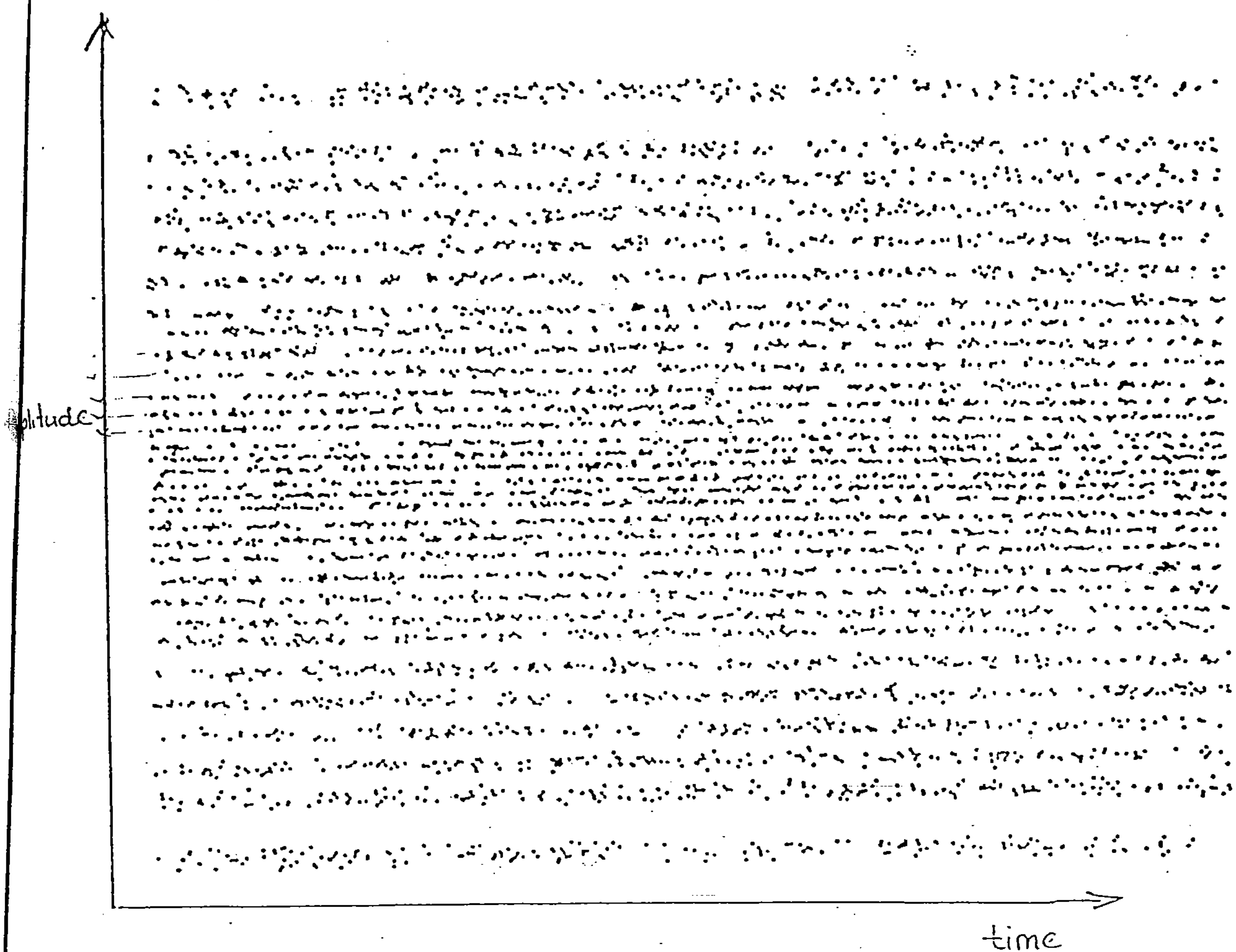

Figure 1 b)

Constellation: 0
Echo Return Loss: 15 dB

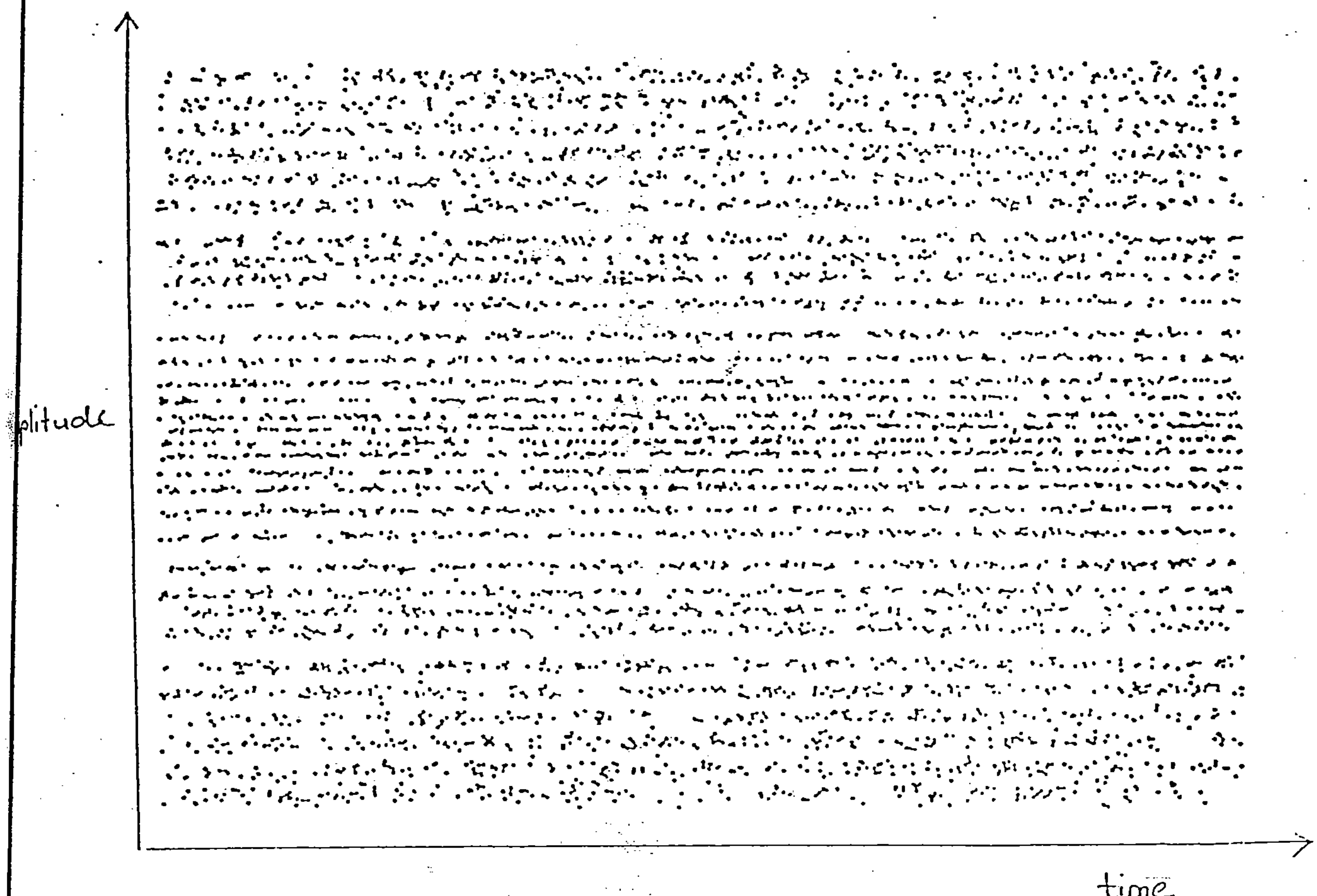

Figure 1c)

Constellation: 1

Echo Return Loss: 10 dB

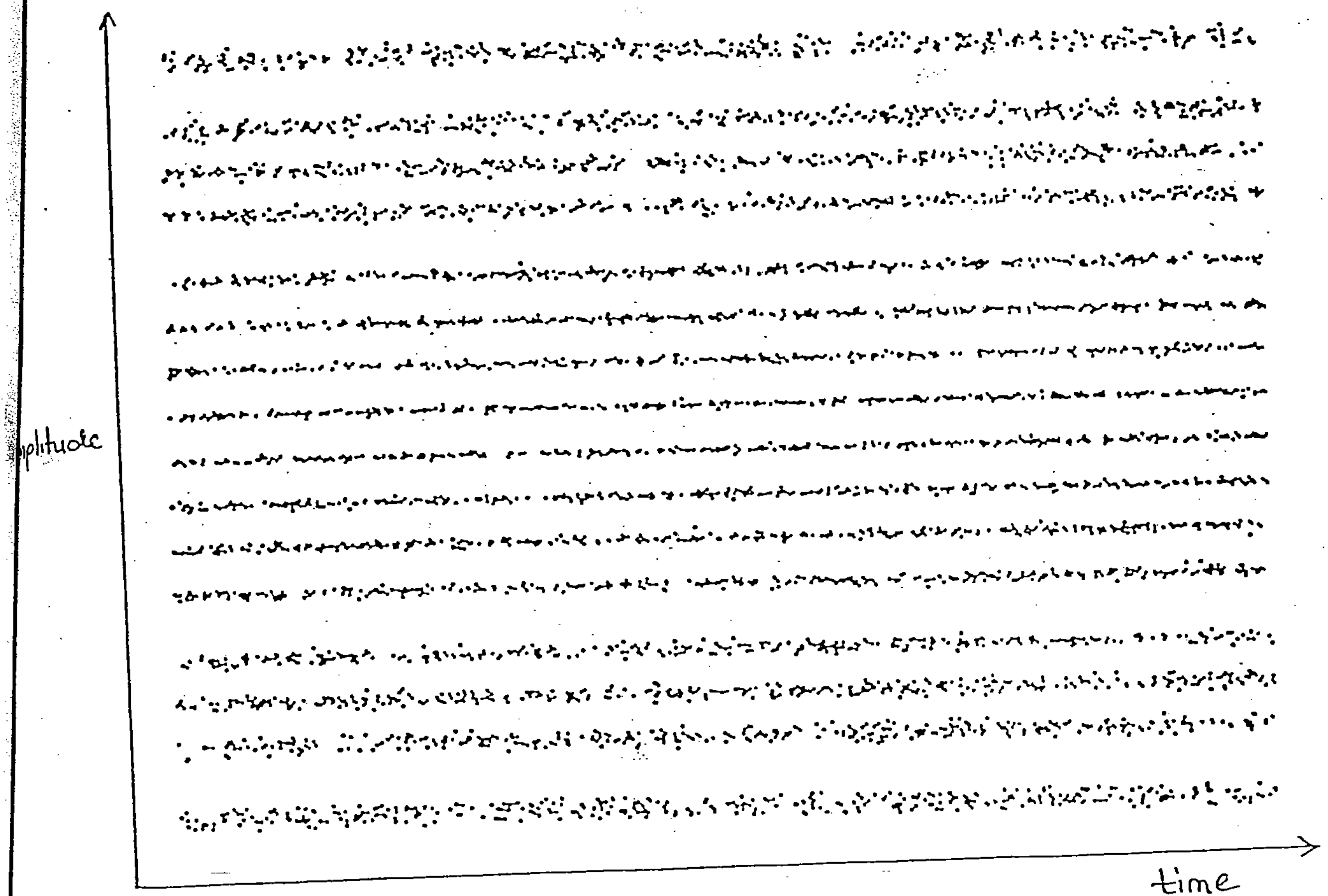

Figure 2a

Constellation: 2
Echo Return Loss: 20 dB

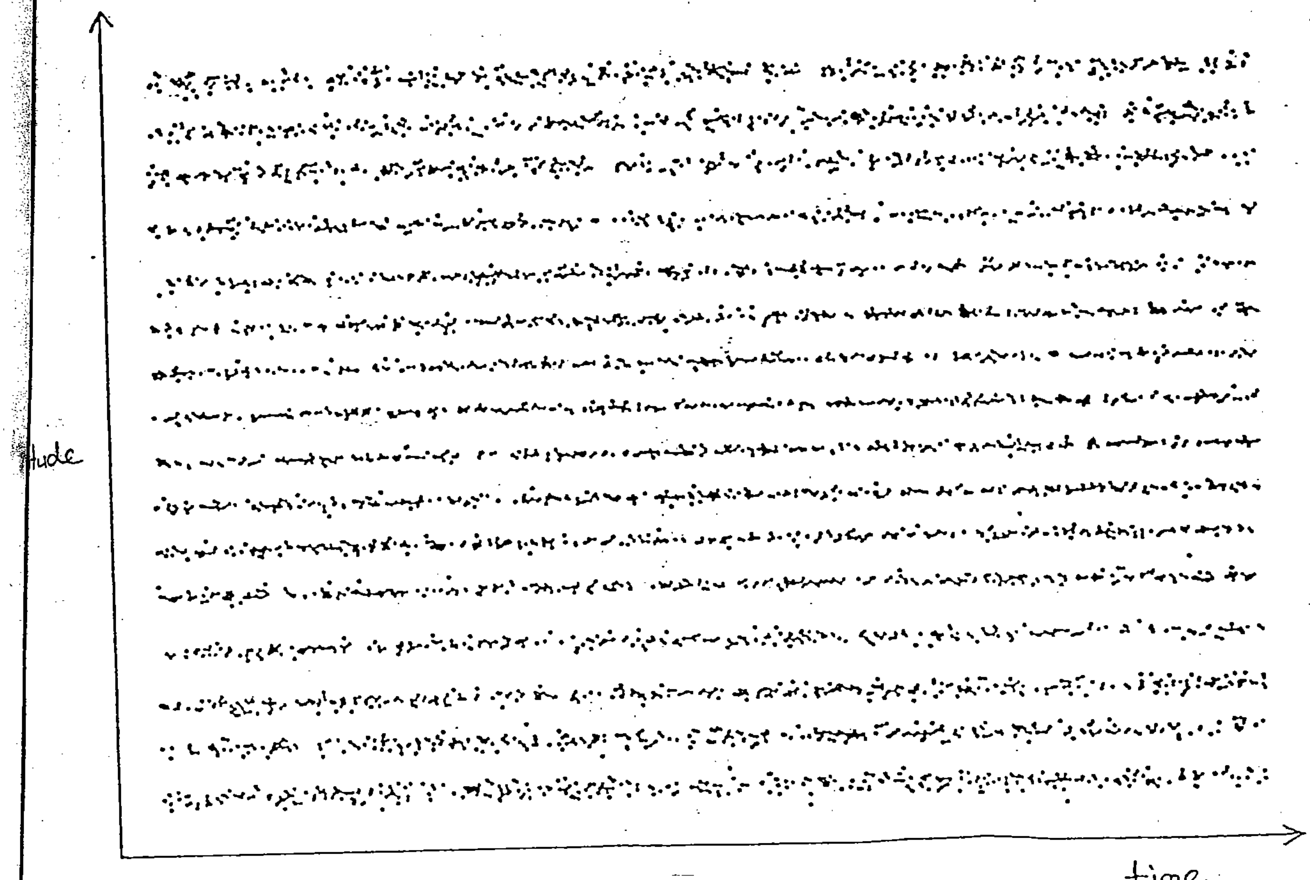

Figure 2b)

Constellation: 2

Echo Return Loss: 15 dB

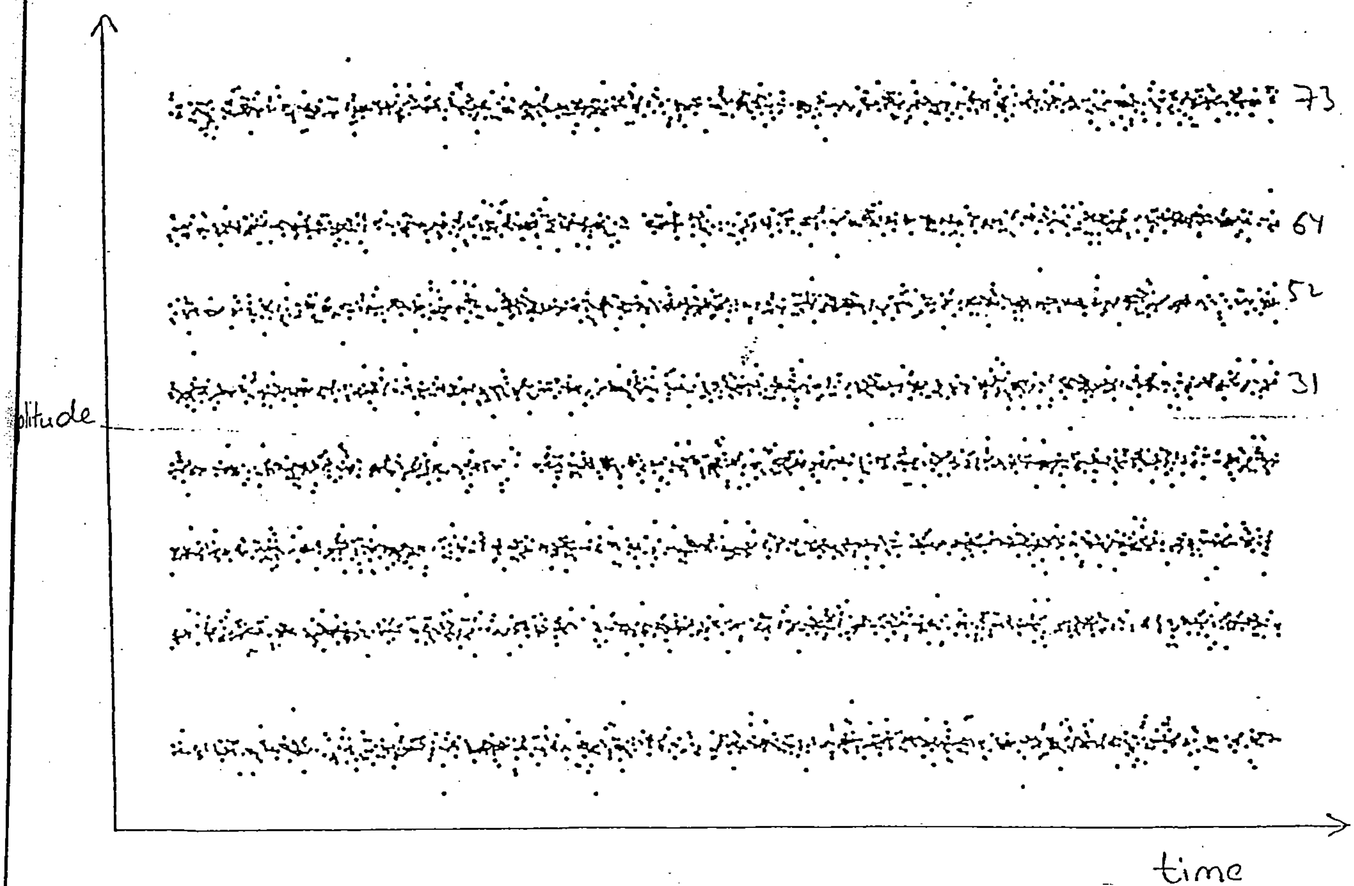

Figure 3

Constellation: 3
Echo Return Loss: 0 dB

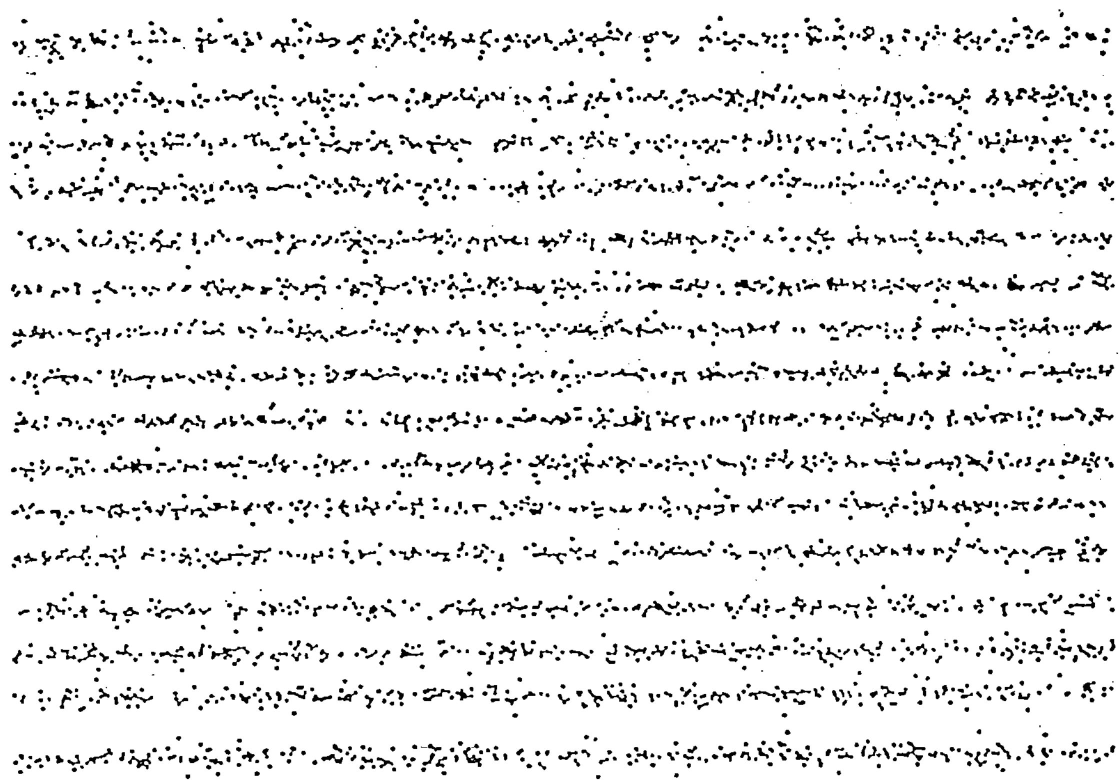

Figure 2c)

Constellation: 2

Echo Return Loss: 10 dB

EXHIBIT P

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Subject: TR30.1 PCM Modem ad hoc meeting report, Irvine California, Nov 13-15 1996

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Lucent Participants: Bahman Barazesh (ME), Nuri Dagdeviren (ME)

Location: Hilton - Orange County airport, Irvine California

Date: November 13-15 1996

Summary

The first PCM modem ad hoc meeting gathered more participants than regular TR30.1 meetings. The meeting mainly focused on the terms of reference for the proposed US interim standard for high speed PCM modems. A total of 16 contributions were presented and discussed during 2 and a half days of meetings. In general the contributions didn't provide much technical detail. 2 contributions from Lucent and Motorola proposed requirements for the US Interim standard. 2 contributions from Motorola and Rockwell proposed solutions for phase 1 of startup to signal V.pcm capability. The Motorola paper included V.8bis which is the Lucent approach. Another significant contribution was from Motorola on a spectral shaping technique for PCM modems. The most technically significant contribution was the Lucent paper on the use of the PCM modulation technique for the upstream direction. This paper generated quite a bit of interesting technical discussion and questions and received good support from many participants. Motorola was first opposed, arguing to use V.34 for the sake of expediency but seemed more open to this approach after the discussion. A third upstream technique called "V.34 Class" was mentioned by USR and Rockwell. The term "V.34 Class", first used in a USR contribution to the October meeting of TR30, seems to describe a V.34-like modulation with less features. It was agreed that the proponents of different upstream techniques will have to submit detailed proposals to the TR30.1 ad hoc meeting December 4-5, in order to be considered for the US interim standard. In the last part of the meeting the editor, Les Brown from Motorola, presented and reviewed a list a agreed points on the terms of reference.

Meeting Report, PCM Modems Ad Hoc meeting, Irvine California Nov 13-15, 1996

General:

Barry O'Mahony from Intel is the chairman of the PCM modem ad hoc committee and Les Brown from Motorola is the editor of the US Interim standard on PCM modems. The next scheduled PCM modem ad hoc meetings are

- 12/4/96, Orlando - Florida, in conjunction with the TR30 meeting
- 1/23 and 24 1997, Fort Lauderdale - Florida, in conjunction with the TR30 meeting
- 1/27/97, Fort Lauderdale - Florida in conjunction with the ITU Rapporteurs meeting (to be confirmed)

This was the first meeting of the PCM modem ad hoc committee. In the October meeting of TR30 in North Carolina, TR30.1 decided to start a project to define a US Interim Standard for high speed PCM modems. It was also decided to form an ad hoc committee that could meet as often as needed in order to progress the work rapidly. The goal of the committee is to approve the Interim standard by August 1997.

The ad hoc committee agreed to focus first on the Terms of Reference and to send the final Terms of Reference along with the Draft of the US Interim standard to the ITU Study Group 16 meeting in March 1997 for information. There was also agreement to work on the Terms of Reference for the ITU PCM modem Recommendation in TR30.1 and to send it to ITU as a TR30 contribution. The ITU Recommendation for PCM modems is expected to offer more capabilities than the US Interim standard.

All of the PCM ad hoc contributions are be available on the following ftp site:

hostname:	world.std.com
user id:	TR301
password:	sensible
directory:	/home/jia/TR301/PCM_Modem

The ad hoc committe propsoed to use the following terms for technical contributions on PCM modems:

digital PCM modem	network side, or central-site pcm modem
analog PCM modem	loop side, or client pcm modem

Contributions:

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Irvine-1 Draft agenda, Barry O'Mahony , chairman ad hoc- Intel

Irvine-2 Proposed preliminary work items list, chairman ad hoc - Intel

Irvine-3 Excerpt from FCC part 68 on server modem signal power limitations, chairman ad hoc - Intel

Irvine-4 DC suppressor for PCM modems - RSA Communications

Irvine-5 Liaison to ANSI T1E1 1.4 TIA TR-41 and TR30.1 on FCC part 68 compliance for "PCM" modems

ASI 035012

Irvine-6 Proposed PCM modem transmitted signal spectrum - Rockwell

Irvine-7 Liaison documents from TR30.3 to TR30.1 on Test Procedures for PCM modems, Jack Douglass - Sierra Semiconductors

Irvine-8 Proposed terms of reference for the high speed PCM modem - Lucent

Irvine-9 Upstream transmission in 64K Modems - Lucent

Irvine-10 Phase 1 startup issues - Motorola

Irvine-11 A spectral shaping technique for PCM modems

Irvine-12 Requirements for the TIA standard on PCM modems

Irvine-13 H.Dispatch - Concepts and Overview - PictureTel Corporation

Irvine-14 Summary of requirements documents - ad hoc committee chairman, Barry O'Mahony - Intel

Irvine-15 Use of an identification sequence for PCM compatible modem identification - Rockwell

Irvine-16 List of agreements reached at the November 1996 ad hoc meeting, PCM modem editor, Les Brown - Motorola

Phase 1

(Irvine-10 and Irvine-15)

The purpose of phase 1 of startup is to signal V.pcm capability and to proceed with V.pcm startup if the remote side supports the functionality or to fall back to existing V.34 and downwards Recommendations. Irvine-10 (Motorola) proposed to either add code points to V.8 or to use V.8bis (several options: non-standard field, network type field or octet3 of data). The V.8bis option is suggested as the preferred solution to support multimedia applications on top of V.pcm. Irvine-15 (Rockwell) proposed to superpose an ID sequence upon ASNam signal at a level 12 to 15 dB below that of ANSam. A similar technique has been used for V.fc, which interfered with some network equipment.

There was more support for V.8/V.8bis approach than the superposed ID signal approach. It was noted that requesting a code point in V.8 for a US interim standard may take a while, and using a new V.8 code point may interfere with existing V.34 modem implementations. Several companies argued that V.8bis was designed exactly for this type of applications. USR expressed concerns that using V.8bis would add 1 to 1.5 seconds to the startup time. There was more support to use V.8bis because of its flexibility and capability to send more information.

The committee didn't reach any agreement on this point, more contributions are invited for the December ad hoc and TR30.1 meeting.

Terms of Reference

(Irvine-8, Irvine-12, Irvine14, Irvine-16)

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Irvine-8 (Lucent) and Irvine-12 proposed an outline for the terms of reference for the US Interim standard on PCM modems. Barry O'Mahony, chairman of the ad hoc committee, generated Irvine-14 which summarizes attributes from the above contributions along with a USR contribution n terms of reference

ASI 035013

to the TR30.1 October meeting. Most of the meeting Thursday was spent on reviewing Irvine-14. Based on the discussions on Irvine-14, Les Brown (V.pcm editor) prepared a summary of agreed points in Irvine-16. This document was presented Friday 12/15. A few corrections and additions were made to the final version of the document.

Spectral shaping

(Irvine-4, Irvine-11, Irvine-6)

It is a well understood problem that DC and very low frequency components in the transmit signal spectrum can not be transmitted through the transformers. Irvine-4 (RSA) proposed two deterministic methods to supress DC in the spectrum. Irvine-6 (Rockwell) presented data on harmonic distortion vs frequency for a specific case that they suggested is typical. The paper proposes to suppress frequency components from DC to 100 Hz by more than 20 dB below the level at 1000 Hz. Irvine-11 (Motorola) proposed a method to shape the spectrum of the transmitted signal by introducing correlation between successive transmitted levels in a probabilistic manner. This paper seems to offer more flexibility to control spectral shaping, and low constellation expansion and received more attention than Irvine-4.

More contributions were invited to the December 96, TR30.1 meeting.

Upstream modulation

(Irvine-9)

The upstream, or client to central-site direction, modulation was first discussed in the October meeting of TR30.1 in North Carolina. In the October meeting, Motorola proposed to use V.34 modulation for the upstream direction because there is no immediate need in this direction for higher speeds than V.34 and using an existing standard would shorten the standardization process. They also argued that there would be many new technical challenges associated with the PCM technique in the upstream that would delay the US Interim standard. In general, most companies agree that using the PCM modulation technique for the upstream is the right technical choice, since it offers higher bit rates that would enable multimedia applications such as audio and video conferencing which require symmetric bit rates. However they argue that it should be considered for the ITU standard and the US Interim standard should use an existing standard for expediency.

During Irvine discussions on Terms of Reference, Motorola reiterated their proposal to use V.34 for upstream direction. While Lucent proposed to use the PCM technique for upstream, USR and Rockwell proposed a third alternative: “V.34 class”. The rationale for using a V.34-like modulation which would be different from V.34 is not clear. Complexity was mentioned by one of the participants, which doesn’t appear to be a major concern. The issue of intellectual property seems to be the motivation for USR and Rockwell to push for a V.34-like ,yet different from V.34, scheme.

Irvine-9 (Lucent) proposed to use the PCM modulation technique for the upstream direction. It presented measured data for a solution, based on a pre-equalizer in the client transmitter and an echo canceller in the central-site, using 16 levels to achieve 32 Kbit/s transmit rate. It also suggested that it would be straightforward to extend this technique to 32+ levels to achieve 40+ kbps on a majority of the loops in the US. The Lucent paper refuted the expediency argument put forward by Motorola to justify the use of V.34 for upstream, and suggested that the PCM technique could be reliably specified within the schedule defined for the US Interim standard. This paper generated quite a bit of interesting technical discussion and questions and received significant support from many participants. After the discussion on Irvine-9,

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many participants seemed more open to the PCM proposal for upstream. One participant noted that instead of spending time on deciding between V.34 and V.34-class, the committee should focus on the PCM approach.

The committee decided that the proponents of different upstream techniques will have to provide detailed technical proposals to the December 4-5 meeting of TR30.1 in Orlando for their proposal to be considered for the US Interim standard.

PCM modems network model, regulatory and performance issues

(Irvine-5, Irvine-7)

TR30.3, also decided in the North Carolina meeting to form an ad hoc committee to focus on various issues related to network modeling and regulatory issues associated with PCM modems. Irvine-7 is a liaison from TR30.3 to TR30.1 which summarizes the TR30.3 ad hoc meeting of November 11 and 12. Irvine-5 is a liaison from T1A1.7 to TR30.1 in response to a request from TR30.1 to provide their views on a number of network issues associated with PCM modems. T1A1.7 stated that they believed the FCC Part 68 requirements are applicable to a modem connected directly to a digital service.